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CANADIAN DIESEL LOCOMOTIVE FUEL IN THE EIGHTIES

Prepared for the

Railway Advisory Committee

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17. Abstract

A review was made of information concerning the future availability of Canadian supplies of diesel fuels for railway locomotives, particularly the "Fuel Supply for Diesel Locomotives" prepared by Hycarb Engineering Ltd. for the Transportation Development Centre of Transport Canada. Meetings were held with the five Canadian suppliers of railway diesel fuel. A visit was made to the Southwest Research Institute to ascertain the status of their program of investigation regarding alternate fuels for medium speed diesel engines. Conclusions were drawn as to action that should be taken by the two major railways to cope with anticipated changes to fuel quality over the next five to ten years.

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17. Résumé

On a fait le point sur les informations relatives aux réserves canadiennes de carburants diesel dont les chemins de fer pourront disposer dans l'avenir pour leurs locomotives; il a notamment été question du rapport intitulé "Fuel Supply for Diesel Locomotives" rédigé par la Hycarb Engineering Ltd. pour le Centre de développement des transports de Transport Canada. Des recontres ont eu lieu avec les cinq fournisseurs canadiens de carburant diesel ferroviaire. De plus, on s'est rendu au Southwest Research Institute pour connaître la situation de leur programme de recherche sur les carburants de remplacement pour les engins de traction diesel à vitesse moyenne. Il en a été tiré certaines conclusions quant aux mesures que devraient prendre les deux principaux chemins de fer du pays pour fair face aux changements qui seront probablement apportés à la qualité des carburants au cours des cinq à dix prochaines années.

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Grateful thanks are also extended to members of the Southwest Research Institute research team for their warm reception and complete explanations of their work on alternative fuels, at the time of the study team's visit to the Institute.

The study team wishes also to acknowledge, with thanks, the assistance provided by the excellent report "Fuel Supply for Diesel Locomotives", prepared by Hycarb Engineering Limited for the Transportation Development Centre of Transport Canada under a contract funded by the Energy Conservation R & D Program of the Federal government.

ABSTRACT

A review was made of information concerning the future availability of Canadian supplies of diesel fuels for railway locomotives, particularly the report "Fuel Supply for Diesel Locomotives" prepared by Hycarb Engineering Ltd. for the Transportation Development Centre of Transport Canada. Meetings were held with the five Canadian suppliers of railway diesel fuel. A visit was made to the Southwest Research Institute to ascertain the status of their program of investigation regarding alternate fuels for medium speed diesel engines. Conclusions were drawn as to action that should be taken by the two major railways to cope with anticipated changes to fuel quality over the next five to ten years.

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EXECUTIVE SUMMARY

Introduction

The principal purpose of this study was to predict the effects on railway operations that may result from changes to the currently specified properties of diesel fuel, identify possible modifications to accommodate the changes and recommend investigations necessary for conversion to use of the new fuels.

The study team reviewed the Hycarb Engineering Ltd. report "Fuel Supply for Diesel Locomotives", and other literature dealing with future availability and properties of railway diesel fuel. Meetings were held with each of five major oil companies in Canada to ascertain their opinions on the subject.

The study team visited the Southwest Research Institute (SwRI) at San Antonio Texas to obtain information as to the status and findings of that institute's ongoing program of investigation into the use of alternative fuels for medium speed diesel engines.

Crude Oil Supply

Canada is currently a net importer of oil to the extent of approximately 15% of its total needs, or in the order of 50,000 cubic metres per day. This shortfall is expected to grow as established reserves dwindle, but subsequently decrease as new frontier and oil sands sources come into production. Canadian self-sufficiency by sometime in the 1990s is being forecast by the federal government.

Future Railway Diesel Fuel Supply Outlook

Security of supply of diesel fuel to current quality is dependent,

not only on sufficient quantities of refinery feedstock, but also on the processing capacity of Canadian refineries and the actual refinery processing configuration. The necessary processing configuration is in turn dependent on:

. the qualities of the feedstock
. the desired mix of product output (market demand)
. the desired product specifications

In Canada, changes are taking place both to the qualities of the refinery feedstock and to the market demand for the product output. These changes are tending to limit the refiner's ability to produce the necessary quantities of diesel fuel to current specifications. The situation is worsened by the fact that the western refineries at present are running at capacity, and their ability to increase output is dependent on construction of planned new facilities between now and 1985. The inclusion of special and costly processing capabilities is an important requirement of those additions and expansions, in order to enable future production of high quality jet fuel and diesel in the face of changes in refinery feedstock and product mix demand.

Notwithstanding these and other uncertainties, in separate meetings with the major oil companies, each company expressed the view that, providing there is no major interruption to the supply of refinery feedstock and no serious interruption to refinery operations, they will be able to supply diesel fuel at, or close to, the railways' current specifications for the next two to three years. A generally similar conclusion can be drawn from the report prepared by Hycarb Engineering Ltd., following their investigation to determine the future availability of diesel fuels for

railway locomotives. The critical need for construction of additional refinery capacity in western Canada was emphasized by both sources.

Important properties of the fuel will change as time goes on, however, necessitating special measures to be taken by the railways to cope with the situation. Implementation of the planned refinery expansion program in the West is of critical importance in ensuring adequate supplies and keeping quality within manageable limits.

Coping With Changes in Fuel Properties

Diesel fuel properties most likely to change are cetane number, distillation end-point and cloud point.

Cetane number

Cetane number is a measure of the ignition quality of a diesel fuel. For a given engine, the cetane number must be high enough to ensure easy starting, even running and efficient combustion. Railway diesel engines are intermediate in size and rpm and so can burn fuels which would be undesirable in automobile, truck and other high-speed diesel engines. Until now, the locomotive diesels have used, along with high-speed engines, a common supply of high cetane number fuel, typically 40 to 50. The current CP and CN specifications for diesel engine fuel call for a cetane number of 40.

While it seems quite certain that there will be increasing difficulty in meeting this requirement, all indications at this time are that it will not drop below 35.

It is not expected that a reduction to 35 would have an adverse effect on normal engine operation. The cetane number of the Suncor gas oil sidestream purchased by the railways for use as diesel fuel is around 35. Canadian railway locomotives have now been operated on that fuel for about 7 years and engine maintenance costs have not been unfavourably affected.

Distillation End-Point

The railways' specifications currently call for a maximum end-point of 350°C (662°F) for winter fuel and 370°C (698°F) for summer fuel. However it has seldom been necessary to accept fuel with an end-point as high as 370°C since refinery practices and distribution systems have in the past required that railway and road transport operators share a common diesel fuel supply. Considerations of fuel price and supply may lead to the production of a separate fuel for railway diesel engines, having a distillation end-point of about 371°C (700°F). In that respect, Suncor have examined the possibility of increasing the end-point of their tar sands product to 371°C (700°F) or even to 399°C (750°F) in order to raise production levels.

The major effect on the engine of an increase in this parameter beyond current limits would be to increase engine deposits and emissions. There would probably be little change if the end-point were raised to 371°C (700°F), but engine maintenance would almost certainly be increased if fuel with an end-point of 399°C (750°F) were used with no other change.

The effects on engine deposits could be alleviated by the use of a

lubricating oil having an increased additive level. The increased engine exhaust emissions that would result might require a relaxation of pollution regulations, or at least a stay on more restrictive changes.

Cloud Point

When a waxy petroleum product is cooled below its cloud point temperature, wax particles gradually crystallize and separate from the diesel fuel oil solution. This formation of wax crystals does not affect engine performance unless the crystals block the fuel filters, in which case the engine will shut down due to lack of fuel.

It can be expected that as time goes on, increasing difficulty will be experienced in obtaining adequate supplies of railway diesel which meets current specifications with respect to cloud point temperature. Primarily, this is due to the sharply increasing demand for low pour (i.e. low cloud point) aviation fuel and automotive diesel fuel, combined with a drop in demand for motor gasoline. As the natural cloud point temperature of the fuel available to the railways during the winter months increases, occurrences of engine shut-down due to blockage of fuel filters will escalate unless preventive measures are taken. Two preventive measures are available, namely the use of "hot-wells" in the engine fuel system and the increased use of "flow improvers" in the fuel itself.

The "hot-well" is a small chamber located so that the fuel must normally pass through it en route to the engine filters. The fuel in the chamber is maintained at a temperature substantially higher than that in the main tank, and has sufficient dwell time to allow wax crystals to pass

back into solution before reaching the filters.

The addition of "flow improvers" (wax crystal modifiers) to the diesel fuel has an effect equivalent to lowering the cloud point of the fuel, thus enabling the successful use of fuel with a natural cloud point temperature higher than would otherwise be possible.

Both major railways are now specifying the application of hot-wells on all new locomotives and both have modification programs underway to retrofit them to existing units. The cost of modification varies from $3000 to $4500 per locomotive. Conversion of the fleets must be completed prior to the time that it becomes necessary to accept fuel with a substantially increased cloud point temperature.

It is believed that through the use of "hot-wells" and newly developed flow improvers, satisfactory cold weather diesel locomotive operation can be maintained with higher cloud point fuel than is currently being received. Heating of lines at wayside storage locations may be necessary.

Alternate Fuels

During their production of synthetic crude oil from Alberta tar sands, Suncor Inc. produce a gas oil sidestream which is suitable for use as railway diesel fuel. All of this sidestream, approximately 1.7 million bbls per year, is purchased by the two major railways and represents about 10% of their total current fuel requirements. Future tar sands developments and heavy oil upgrading plants may offer a potential for the railways to obtain additional supplies of diesel fuel similar to that gas oil sidestream.

Certain gases, alcohols, coal derived liquids and coal slurries represent potential alternate fuels for the diesel engine, at least theoretically. None, however, are close to being utilized successfully in railway diesels although work on alcohols is included in the SwRI program. Conversion to electrified operation, although technically feasible and possibly economically viable from the standpoint of the nation as a whole, does not appear to be a commercial possibility for the railways at this time. As traffic levels and diesel fuel costs increase, its commercial attractiveness will increase.

Principal Conclusion

Canadian railways can cope with the changes to diesel fuel properties that are likely to occur over the next five to ten years, without significant losses in operating effectiveness. To do so

(i) will require the installation of hot-wells.

(ii) will require the increased use of flow improvers.

(iii) may require the use of heated railway cars for delivery of diesel fuel to wayside storage tanks at remote locations.

(iv) may require the heating of lines from fuel storage tanks to locomotive fuelling stands.

(v) may require some increase in the amount of engine maintenance.

1. INTRODUCTION

In recognition that present day uncertainties in the petroleum industry may lead to constraints in the continued production of diesel fuel of current quality, the Railway Advisory Committee on research in the railway mode proposed that studies be undertaken to investigate the possible need for, and consequences of, utilizing diesel-like fuels which have properties outside of the tolerance of current specifications.

The work required expertise from both the refinery and railway industries and it was therefore separated into Study A and Study B. Following are the specific project objectives of each, taken from the Study Work Statements.

Study A

To identify and define:

a) the likely characteristics and other relevant information concerning the conventional diesel fuel(s) which, because of changes in refinery production, Canadian railways may be forced to use by 1985 or soon thereafter;

b) the changes (if any) that, because of changes in product characteristics or other reasons, may be required to the present system for the distribution of the fuel from the refineries.

That investigation was funded by the Transportation Development Centre of Transport Canada (TDC), who retained Hycarb Engineering Ltd. of Calgary, Alberta, to accomplish the work. Hycarb's report on their work and findings, dated October, 1980, is entitled "Fuel Supply for Diesel Locomotives" and, along with a separate summary report, is available through TDC.

Study B

a) to predict the effects on diesel engine performance, and on railway transportation, fuel storage facilities and handling procedures, of changes to the currently specified properties of diesel fuels and identify possible modifications to accommodate the changes.

b) to recommend a program of experimentation and other investigations necessary for successful conversion to use of new fuels by the railways.

This work was funded jointly by CP Rail and CN Rail and was carried out by a small committee of railway officers. This document constitutes the report on their investigations and findings.

Early in the course of their work, the Study B members visited the Southwest Research Institute (SwRI) at San Antonio, Texas. Purpose of the visit was to obtain information as to the status and findings to date of the SwRI program of investigation into the use of alternate fuels for medium speed diesel engines. Information regarding the background and status of the SwRI program may be found in Appendix A of this report.

The Study B committee held separate meetings in Montreal with representatives of each of the five major oil companies in Canada to obtain their views as to the short and medium term outlook for the continued supply of the necessary volumes of diesel locomotive fuel. Meetings were held as follows:

Sept. 16, 1980 - Imperial Oil Ltd.
Oct. 2, 1980 - Texaco Canada Inc.
Oct. 22, 1980 - Shell Canada Ltd.
Oct. 30, 1980 - Suncor Inc.
Nov. 13, 1980 - Gulf Canada Ltd.

A summary of the significant relevant information obtained at those meetings, augmented by data and information from the Hycarb Engineering Ltd. report is included as Appendix C of this report.

2. DIESEL FUELS AND ENGINES

2.1 General

Conventional diesel fuels are distillates with a boiling range of about 149°C to 371°C (+ 300°F to + 700°F) obtained by the distillation of crude oil. These fuels are predominantly straight-run fractions but may contain some cracked material under special conditions and/or applications.

In a broad sense, engine speed determines the type of fuel best suited for the engine. The higher the engine speed the more sensitive the engine is to cetane number, distillation end-point, and other characteristics. Fuel characteristics are inter-related and no one characteristic can be used to define a fuel's quality or performance.

Diesel engines are designed to provide maximum performance on a specific grade of fuel. The engine builder usually recommends the type of fuels for his engine and this fuel recommendation may be to his own specification or a reference to accepted standards, such as those developed by the American Society for Testing and Materials (ASTM). The ASTM have set minimum quality standards for diesel fuel grades, under ASTM Specification D-975 (Appendix B - Figure 1). These are grades No. 1-D, which basically specifies winter fuel, and No. 2-D, which outlines summer fuel.

2.2 Categories of Diesel Engines

Diesel engines are separated into three broad categories - slow speed engines, medium speed engines, and high speed engines. The boundaries between these categories are not readily defined, but those under 250 rpm can be considered slow speed, from 250 to 1100 rpm as medium speed, and above 1100 rpm as high speed.

Large Slow Speed Engines

The slow speed engines are the type used in marine service. Some produce in excess of 40,000 hp. Rotational speed is in the order of 110 to 125 rpm. They are designed to burn economical, residual type fuels.

Medium Speed Engines

These engines, depending on design and application, can operate on a wide variety of liquid fuels ranging from light distillate to heavy intermediate fuels. They develop horsepower in the range from approximately 1000 to 18,000 with rotational speeds ranging from 250 rpm to 1100 rpm. This type of engine encompasses the widest field of application, being used for power generation in railroad motive power, stationary power plants, marine propulsion and auxiliaries, and other applications where its adaptability makes it the most popular form of power.

The medium speed, low-weight-to-horsepower railway diesel engine develops horsepower in the range from 1000 to 4000 non-turbocharged or turbocharged, with rotational speeds from 900 to 1100 rpm.

High Speed Engines

A wide variety of engines are available in the so-called high speed range which is considered as indicating those engines above 1100 rpm. The dominant engine is the conventional 4-cycle automotive type. In this field there are engines which range up to 2500 hp employed in trucking, marine, construction and industrial applications.

2.3 Engine Ignition Characteristics

The diesel engine is unlike the gasoline engine where a carburator is used to maintain a fairly constant ratio between air intake and fuel input throughout the speed range of the engine and where ignition is achieved by a spark. The diesel engine utilizes rapid compression of air in the cylinder to a high pressure, thus raising the air temperature to such a point that the fuel, when delivered into the combustion chamber, spontaneously ignites without depending on a spark to initiate combustion.

In the diesel engine the spark plug is replaced by a fuel-injection valve and the compression ratio is increased to about 15 to 1. Alternatively, some engines use surface ignition In these types of engines medium compression is employed and ignition is activated by use of a hot bulb glow plug or plate located in the combustion chamber.

2.4 Diesel Fuel Requirements

The general requirements for a good diesel fuel are as follows:

(i) Knock Characteristics - The present day measure is the cetane rating - the best fuel, in general, will have a cetane rating sufficiently high to avoid objectionable knock

caused by excessive rate of pressure rise.

(ii) Starting Characteristics - The fuel should start the engine easily. This requirement demands high volatility, to readily form a combustible mixture, and a high cetane number in order that the self-ignition temperature will be low.

(iii) Smoke and Odour - The fuel should not promote either smoke or odour from the exhaust. In general, good volatility is demanded as the first prerequisite to ensure good mixing and therefore, complete combustion.

(iv) Corrosion & Wear - The fuel shall not cause corrosion before combustion, or corrosion and wear after combustion. These requirements are directly related to the sulphur, ash, and residue contents of the fuel.

(v) Handling Ease - The fuel should be a liquid that will flow readily under all conditions that will be encountered. This requirement is measured by the cloud and pour points and the viscosity of the fuel. The fuel should also have a high flash point to minimize fire hazards.

2.5 Diesel Fuel Specifications

The ASTM grades 1-D and 2-D covered by ASTM specification D-975 previously referred to (Figure 1 - Appendix B), are very broad, and the diesel fuels marketed in Canada will meet this definition. The Canadian Government 3-GP-6M diesel fuel specification identifies five categories

of fuels with more restrictive standards than ASTM. Diesel engines that require the use of fuels meeting ASTM-D-975 will be satisfied by the corresponding type of fuel to the 3-GP-6M standard (Figure 2 - Appendix B). Type AA and A relate to No. 1-D requirements; types B, C and D relate to No. 2-D fuels.

Railway Diesel Engine Requirements

As previously stated, an engine builder usually recommends the type of fuel for his engine. The two Canadian railway engine manufacturers are no exception, and both General Motors Diesel Division (EMD) and Bombardier Inc. (Rail and Diesel Products Division) provide their recommendations (Figures 3 and 4 - Appendix B). These recommended limits for fuels are specific in certain categories that have a direct effect on engine output and performance. Parameters related to fuel handling, such as flash point, cloud and pour points, are dictated by government and user regulations and ambient operating temperatures.

The major Canadian railways, CN Rail and CP Rail, issue diesel fuel specifications designed to satisfy the respective engine builders' recommendations, regulatory safety regulations and operating conditions. Both of these specifications issued, CN Rail (Figure 5 - Appendix B) and CP Rail (Figure 6 - Appendix B), designate a summer and winter fuel oil requirement. A premium quality product with lower cold temperature properties is essential for reliable operation during Canada's winter season.

Deviation from Current Railway Fuel Specifications

The American Society for Testing and Materials have proposed a

No. 3-D fuel specification (Figure 1 - Appendix B). The objective of adding the No. 3-D fuel to their D-975 specifications is to extend the total volume of distillates available by allowing the use of refinery streams that are not suitable for use in the more restrictive No. 2-D fuel. The specification carries the disadvantage of allowing a higher sulphur level. No. 3-D fuel is designed for use in those engines that normally use No. 2-D fuel but could tolerate a higher boiling range, lower cetane fuel.

It is the belief that with minor modifications and the use of high additive level lubricating oils, the railway diesel locomotive engine could utilize this No. 3-D fuel, or a product with similar physical properties, with limited adverse effects. By utilizing fuel conforming to this broader specification, distillate fuel availability could be increased considerably.

2.6 Fuel Properties and Engine Performance

There are four properties of diesel fuel which have a major effect on engine performance; namely, cetane number, distillation range, viscosity and amount of sulphur content.

Cetane Number

Cetane number is a measure of the ignition quality of a fuel and proper cetane number is basic to the efficient burning of fuel in an engine. For a given engine the cetane number must be high enough to ensure easy startability, even running and complete efficient combustion. Generally, larger engines are slower running, giving more time for complete combustion and allowing use of a lower cetane number fuel. It should be noted that

fuels having a high octane number have a low cetane number and thus are unsuitable for use in diesel engines.

Railway diesel engines are intermediate in size and rpm and consequently can burn fuels which would be undesirable in automobile, truck and other high-speed diesel engines. Until now, the locomotive diesels have used, along with high-speed engines, a common supply of high cetane number fuel, typically 40 to 50 cetane number. A change to lower cetane number fuel may involve a trade-off in engine performance, maintenance costs and engine life. A small drop in cetane number, to say 35, would produce no easily measurable change in engine performance while a large drop, to say 25, would likely be intolerable, involving a loss of power. At cetane numbers of about 20, bearing damage due to uneven running could lead to catastrophic failures with current engine designs. Engine redesign to tolerate lower cetane number fuel would be difficult and would result in a reduction of power output.

As is discussed in Chapter 3, supply constraints are tending to decrease the cetane number of fuel for railway diesel engines. However, because of the basic importance of cetane number in obtaining satisfactory engine performance, such decreases must be limited.

Distillation Range

Properties of the lighter more volatile fuels are such that they distill at temperatures lower than do the heavier less volatile fuels; i.e. the higher the distillation temperature the heavier and less volatile is the distillate. Thus the maximum permissible upper end of the distillation range (distillation end-point) for any fuel is set by the need to obtain complete combustion in the particular type of engine in which it is

to be used, especially under idle or light loads. Incomplete combustion can lead to ring groove deposits, smoke, and emission problems. Since the larger, slower engines allow more time for combustion to be completed, such engines can use heavier fuels satisfactorily.

Refinery practices and distribution systems have in the past required that railway and road transport operators share a common diesel fuel supply. Considerations of fuel price and supply may lead to the production of a separate fuel for railway diesel engines, having a distillation end-point of about 700°F (371°C). This might result in an increase in lubricating oil costs, as an oil with more additive will be required to control ring groove deposits.

Viscosity

The fuel used in an engine must have suitable viscosity. Too low a fuel viscosity may cause injector wear due to lack of lubrication. Too high a viscosity may result in poor fuel atomization and combustion. Wear due to low viscosity can be controlled economically by a lubricity additive and heavy fuel can be preheated to reduce viscosity before atomization. However, it appears probable that the viscosity of fuel available for railway use in the next few years will continue to fall into the range of current specifications and will present no problems.

Sulphur

Amounts of sulphur in Canadian diesel fuel currently run about 0.3% and engine wear is kept under good control with existing levels of additive in engine crankcase oils. Increase of sulphur level to 0.5% will

result in an increase in lubricating oil costs. Up to 0.7% sulphur fuel can be tolerated with a further increase in lubricating oil additives and resulting increase in costs. Above 0.7% sulphur, power assembly wear rates would probably be unacceptable.

Other Fuel Properties

In addition to the four basic fuel properties, other properties, such as flash point, cloud and pour points, require mention. Low flash point fuels involve consideration of safety. Flash points below 40°C (104°F) should be avoided; otherwise fuel handling procedures and regulations will require modification.

Pour point of the fuel is the lowest temperature at which it will pour or flow when it is chilled without disturbance, under prescribed conditions. Cloud point is that temperature at which wax starts to crystallize out of solution - typically 10°F higher than the pour point. To avoid blockage of fuel filters by the wax particles, engine modification in the form of hot-wells (Chapter 5) and flow improver additives (Chapter 4) are required when the fuel's natural cloud point temperature is too high. Modifications to wayside handling practices, or the use of fuel additives will be required when the fuel temperature falls below its pour point.

As the amount of Tar Sands synthetic crude oil increases in refinery feedstock, the diesel fuel produced will be increasingly aromatic. Inasmuch as aromatic hydrocarbons can dissolve more water than aliphatic or straight-chain hydrocarbons, there will be more dissolved water in future

fuels and a worsening in fuel handling problems due to the presence of water or ice. While small amounts of water can be tolerated, large amounts of free water must be removed by frequent draining of bottoms from storage and locomotive tanks. Nevertheless, some water will remain in the fuel and at low temperatures will result in ice formation. Pre-heating, through use of hot-wells, will eliminate ice as a fuel filter blocking problem. The use of alcohol, presently added to locomotive fuel tanks as a de-icer, can be discontinued. This will result in savings in labour and methanol and avoid potential fire risks associated with methanol.

3. FUTURE RAILWAY DIESEL FUEL SUPPLY OUTLOOK

3.1 Crude Oil Supply

An adequate and secure supply of refinery feedstock (crude oil and equivalent) is an obvious requirement for the production of sufficient quantities of diesel fuel and other petroleum products. Although Canada has a large surplus of natural gas, the country currently is a net importer of oil, to the extent of approximately 15% of its total needs or in the order of 50,000 cubic metres per day (m^3/d). This shortfall is expected to grow as established reserves dwindle, but subsequently decrease as new frontier and oil sands sources come into production and demand falls as a result of conservation measures. By sometime in the 1990s self sufficiency is expected (1).

Current differences between Ottawa and the western provinces regarding pricing policy appear, at least to the non-expert, to be setting back the point of self sufficiency. Whether or not this is the case, it appears that barring a dramatic and unexpected drop in demand, the nation will continue to be dependent on foreign sources for a portion of its crude oil for a minimum of 10 - 15 years. The long lead time required in the present Canadian circumstances, between identification of new proven reserves and an increase in refinery products supply, effectively precludes any early relief from that direction.

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(1) See Figures 1 - 4 inclusive, Appendix C.

In the event of a major disruption in supply, the railways, like all other industries, will be dependent on the federal government's fuel allocation system.

3.2 Factors Affecting Refinery Output

As is discussed in the Hycarb report and as was noted by the oil companies during the study team's meeting with them, security of supply of diesel fuel to current specifications is dependent on more than simply the availability of sufficient quantities of refinery feedstock. It is a function also of the crude running capacity of Canadian refineries and the actual refinery processing configuration. The necessary processing configuration is in turn dependent on:

- the qualities of the feedstock
- the desired mix of product output (viz. market demand)
- the desired product specifications

Changes are taking place which affect the first two of these factors. As to the qualities of the feedstock, the availability of conventional western Canadian light crude oil is declining, with a consequent need for the refiner to utilize increasing volumes of heavier imported crudes which are also generally higher in sulphur content, and/or increased quantities of synthetic crudes which, although lower in sulphur, it is expected will be higher in aromatics and consequently lower in cetane value. At this time the quality of frontier oil from the Beaufort Sea and the east coast regions of Canada is uncertain. For purposes of their analysis, Hycarb assumed that it will be comparable to the average quality of imported crude presently being processed in Eastern Canada. If this assumption is

generally correct, then as that oil comes on stream, it too will impact adversely on the quality of the refinery feedstock.

Significant changes are also taking place in the market demand for refinery products and the trends are forecast to continue. The demand for low pour point aviation jet fuel and automotive diesel fuel has been increasing sharply[1] while at the same time, demand for motor gasoline, heating oil and heavy fuel oil is decreasing. The drop in demand for motor gasoline limits the refiners' flexibility to reduce the gasoline/distillate ratio in order to produce greater quantities of diesel. Although in some refineries, operations can be adjusted to produce more distillate at the expense of gasoline, that distillate is very low in cetane number (in the order of 22-27 according to Hycarb) and thus, if used for blending of diesel, reduces the average cetane number of the diesel pool.

Similarly, the properties of the surplus heating oil stocks are such that when used to fill out diesel supplies, the cetane number of the pool is lowered. Additionally and probably more critically, the cloud point temperature of the pool is increased.

Contributing further to the uncertainty regarding future supplies of diesel fuel, is the fact that the western refineries are at present running at capacity and their ability to increase output is dependent on construction of planned new facilities and expansions between now and 1985. The inclusion of hydrocracking and other special and costly processing capabilities is an important element in those additions and expansions in

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(1) It seems reasonable to expect that rapidly rising prices will curtail the demand for aviation jet fuel.

order to enable future production of high quality jet fuel and diesel in the face of the previously noted changed in refinery feedstock and product mix demand.

3.3 Future Supply of Diesel Oil

Notwithstanding these uncertainties, the picture regarding the future supply of diesel oil gathered from the Hycarb report and from the study team's discussions with the major oil companies is not unduly alarming. It is significant though, that the critical need for construction of additional refinery capacity in western Canada was emphasized by both sources. It is perhaps also significant that the new National Energy Policy was announced subsequent to preparation of the Hycarb report and subsequent to the study team's meetings with three of the major oil companies. The meetings with the two other companies followed too soon after announcement of the policy to enable any recognition of it to be embodied in what was said regarding the future. A review of the situation today might result in a more pessimistic supply outlook.

With respect to future supply of diesel oil, the Hycarb report included the following conclusions:

> "In western Canada, the refining industry is characterized by a near-term shortage in refining capacity. Product supplies are forecast to be tight and imports may be necessary to alleviate deficits. Diesels are forecast to be in tightest supply, particularly the low pour diesels. In the longer term, announced refinery additions should enable the refining industry to meet product demand.
>
> "In eastern Canada, the short-term situation is tight but manageable. The medium to longer term, however, may present the refining industry with difficulties. The situation is not one of refinery throughput limitations, but refinery processing configuration. The refining

community has ample crude running capacity to meet product demands throughout the forecast period. The industry appears to have insufficient processing flexibility, however, to meet current quality specifications as the product mix changes in the marketplace.

"The problem appears to be one of balance in the middle distillate pool. With a forecast decline in the market demand for LFO*, increased throughputs of synthetic crudes and additional LFO production from potential HFO** upgraders, the refineries face surpluses of LFO and shortages of high quality diesel, particularly low pour diesel."

In the meetings held with the major oil companies, each company expressed the view that providing there is no major interruption to the supply of refinery feedstock and no serious interruption to refining operations, they will be able to supply diesel fuel at or close to the railways' current specifications for the next two to three years. One company foresees no significant change in Canadian diesel fuel quality for the next five years.

3.4 Cetane Number and Cloud Point

It is abundantly clear, however, that even assuming no major interruption to the supply of imported crudes, the railways are going to be faced with increasing difficulty in obtaining adequate supplies of high cetane number, low pour point diesel fuel as time goes on. The situation in western Canada will be relieved as the planned new refinery facilities there come on stream, but it is not entirely clear now that plans made before announcement of the government's new energy pricing policy will all become realities.

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* LFO - light fuel oil
** HFO - heavy fuel oil

There are apparently no plans for extensive additions and alterations to the eastern refineries. Although refinery running capacity in the East is ample to meet demand projections, there will be difficulty, due to limitations in refinery process configurations, in producing the product mix required to meet the changing market demand. As the demand for diesel fuel increases and for light fuel oil decreases, it is forecast that the refinery industry will find it necessary to dilute the diesel pool with more and more of the surplus fuel oil with consequent lowering of cetane number.

The situation with respect to cetane number is complicated by the requirement of 45 for automotive fuel. So far, it appears that a special grade of diesel having a cetane number of only 40 to meet railway specifications is not being blended by the refiners although this could be done for summer fuel when cloud point is not so critical. However, for winter fuel, a low pour light fuel oil would have to be used for blending to avoid raising the pour point of the mixture, and there is no surplus of that product, at least at this time.

The shortage of low pour blending stocks could be eased by extending the season for the use of summer diesel, or by blending an intermediate quality diesel for spring and fall use. This could be done on the basis of overall diesel supply rather than just for railway diesel, thus avoiding the need for additional tankage and special handling, which would otherwise be required. Extra tankage might be required at remote locations where, because of low turnover, users might otherwise be caught without low pour diesel in the event of a sudden change in temperature.

Although it is clear from the discussions with the oil companies and from the Hycarb report that the cetane number of railway diesel fuel will almost surely decrease commencing in 1982 or 1983, and cloud point increase, the amount of change which is likely to occur and the time period during which the change might take place is uncertain. Insofar as cetane number is concerned, no figure lower than 35 was mentioned seriously by the oil companies, so it could perhaps be taken as the lower limit. Hycarb does not forecast the cetane index dropping below 41 or 42 (equivalent to a cetane number of approximately 38 to 39).

On the question of cloud and pour points, the possibility of using summer diesel all year round is discussed briefly in the Hycarb report and also came up in the discussions with at least one of the oil companies. Beyond that, and except for the possibility introduced by one company for an eventual potential requirement to live with a pour point of +5°C and a cloud point of +10°C, no specific values were forecast by the oil companies for this important parameter.

Hycarb forecasts an increase in pour point of 2 - 3°C (approx. 5°F) between 1980 and 1982 in both western and eastern Canada with the probability of an easing in the longer term. In that respect though, it was noted that in eastern Canada, the situation is "extremely tight" and "the ability to meet pour point specifications will vary with the refiner's particular circumstance".

Action that will be necessary to cope with these changes to diesel fuel properties is outlined and discussed in Chapter 5.

3.5 Increasing the Supply

The possibility of increasing diesel fuel quantities by raising the distillation end-point was noted by most of the oil companies and by Hycarb. The Hycarb report states (page 67) that: "By raising the end-point specifications from say 343°C (650°F) to 357°C (676°F), by cutting deeper during refinery distillation, diesel stocks could be increased by 10-12%. Such an increase would increase the pour point of the stock by 2-3°C (approx. 5°F). Similarly, an increase in end-point from 350°C (662°F) to 364°C (687°F) would have the same effect". The report also notes that through the use of pour point depressants, the pour point of the 343° - 357°C cut (650°F - 676°F) would be kept unchanged. However, the cloud point would increase. It seems highly likely to the study team that the necessity to increase railway diesel fuel supplies will lead to a requirement for the railways to accept a higher distillation end-point.

The Hycarb report recommended (page 71) that the railways "should continue to pursue the receipt of synthetic stocks for use as diesel. The railways may have the opportunity to secure additional GCOS[1] gas oil as part of the GCOS expansion". The reference here is to the gas oil sidestream produced by Suncor Inc. during their production of synthetic crude oil from the Alberta tar sands. All of this sidestream (approximately 1.7 million barrels per year) is purchased by CN Rail and CP Rail for use as diesel locomotive fuel.

At the time that the study team met with the Suncor representatives, changes to increase the present level of output of the gas oil sidestream were being considered. One possibility was to change the end-point from

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(1) Great Canadian Oil Sands

650°F (343°C) to 700°F (371°C). Another was to change it to 750°F (399°C) and also change the API gravity from its present 30° - 40° to 25° - 35°. It was estimated that such changes combined with certain plant alterations and storage tank additions, would by 1984, enable production to be increased from its present 1.7 million bbls per year to 2.5 million bbls. Consideration was also being given to achieving the same 1984 production level through more costly plant alterations and leaving the product specifications unchanged.

The present production of 1.7 million bbls annually represents approximately 10% of the total Canadian railway usage of diesel fuel. An increase of 0.8 million barrels in this source of supply by 1985 would go a long way towards offsetting the predicted increase in demand for railway diesel fuel by that date - estimated variously to be between 1.2 and 3.7 bbls/year (500 to 600 m^3/d).(1) However, it is not clear at this time whether Suncor's plans for expansion are in fact to be implemented.

A second tar sands plant for the production of synthetic crude oil is now in operation, by Syncrude Canada Ltd. However, the Hycarb report points out that: "Unfortunately, Syncrude does not have available a stream equivalent to that of GCOS. Although Syncrude does have the equipment to provide a diesel cut from the plant, the nature of the processing probably renders that stream unsuitable. Syncrude's upgrading process is based on fluid coking, as compared with delayed coking at GCOS. Fluid coking is a more severe cracking operation than delayed coking. The distillate from Syncrude would have a cetane number in the low 20's.

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(1) Appendix C - Table 3

"Potential does exist to obtain low quality diesel fractions, perhaps similar to GCOS, from future tar sands and heavy oil upgrading plants. These plants are complex and have many streams which flow between the various processing units. For example, some streams may require recycling to improve their quality prior to being acceptable as synthetic crude oil. Recycle adds to the investment and operating costs of the plant. The recycle stream may be of a quality acceptable to the railways as diesel. If the railways were to approach the planners of future upgrading ventures, they may very well be able to secure supplies to the mutual benefit of both parties."

Notwithstanding the above, the railways should obtain more information on the Syncrude production, to enable an assessment to be made of the suitability of any of the Syncrude fractions as a diesel fuel.

Further on the matter of increasing supply, the Hycarb report also notes that diesel quantities could be increased by lowering the flash point. The present flash point specification for automotive diesel is 51.7°C (125°F) compared to 40°C (104°F) for railway diesel. An 11.1°C (20°F) decrease in flash point would increase the volume of a 177°-343° (350°-650°F) cut by approximately 15%.

3.6 Summary

Assuming no major interruptions to the supply of crude oil and no serious interruptions to refining operations, it appears there will be sufficient quantities of diesel fuel to current specifications available to Canadian railways for the next two to three years. Important properties of the fuel, principally cetane number, cloud point and distillation

end-point, will change as time goes on however, necessitating special measures to be taken by the railways to cope with the situation.

Implementation of the planned refinery expansion program in the West is of critical importance in keeping fuel quality within manageable limits.

Future tar sands developments and heavy oil upgrading plants may offer a potential for the railways to obtain additional diesel fractions, perhaps similar to the gas oil sidestream already being produced by Suncor. The railways should discuss this possibility with the planners of such developments and for the same reason, should obtain more information on the Syncrude production.

4. FLOW IMPROVERS

4.1 Background

Wax crystal modifiers have been utilized for twenty years or more to improve the flow characteristics of waxy crude oils and petroleum products. In Canada, the use of flow improvers for diesel fuels began in 1962 with the availability of Paradyne 25 to gain a 5°F improvement in cold weather operability. Commencing in 1965 some fuels so treated were supplied to the railways. The introduction of flow improvers in Canadian railway diesel fuels coincided with the entry of "cracked" components to the previously supplied "straight run" distillate stream.

During the period 1970-75, a new generation of flow improvers was evaluated in Minnesota and better laboratory/field test correlations were obtained.

The exact mechanism by which improvement in flow characteristics is achieved is not completely known but there is a general understanding of the phenomenon. When a waxy petroleum product is cooled below the cloud point, wax particles gradually crystallize and separate from the diesel fuel solution. The thin plate or needle-like crystals agglomerate to form a loose gel structure. The addition of flow improvers or wax crystal modifiers tends to prevent or retard this agglomeration by changing crystal size and shape and crystal to crystal interaction, thereby reducing the temperature at which the gel structure is formed. Avoidance of agglomeration permits wax crystals to flow through fine filters thereby reducing the filter flow constraint.

4.2 New Flow Improvers

To date the "state of the art" of flow improvers in diesel fuels has been limited to fuels with cloud points near or above -23°C (-10°F). It has become apparent from initial field applications and recent information from the principal diesel fuel suppliers that a "third" generation of flow improvers now under development may well offer significant improvements in performance. Current indications are that the operability range may be extended to 11°C (20°F) below the particular fuel's natural cloud point with an additive concentration of .08% by volume. However, in the lower temperature ranges greater additive concentration is needed. Presently it is now known how to obtain effective flow improvement economically by applying additives to a -32°C (-25°F) cloud fuel to obtain operability at -40°C (-40°F).

Tests conducted by Imperial Oil on non-railway applications at four test locations: Amherst, New Glasgow, Rimouski and Baie-Comeau during the period 1977-1980 gave good correlation between laboratory and field test experience. The results have confirmed a 15-25°F (approx 8-14°C) operability below the cloud point, which is equivalent to a 35-50% kerosene addition. Additionally, the water shedding characteristics of the treated fuel were found to be equivalent to that of natural diesel fuel. Additive concentration levels are economically attractive.

If the effectiveness of the new third generation flow improvers can be conclusively demonstrated for railway operation, a number of significant possibilities exist. One immediate benefit is an apparent ability to compensate for a departure from current diesel fuel specifications with regard to cloud point. There has been a good deal of discussion

both in the United States and Canada concerning the desirability of moving toward a single or "all year" diesel fuel product. A more effective flow improver, such as that now being considered by the principal oil companies, may permit the use of such an "all year" product, with specifications more closely related to the current summer diesel fuel requirements.

Diesel fuel suppliers have indicated they are most anxious to stretch summer diesel which has a cloud point of -4°C (+25°F), as far as possible into a year round fuel through the use of a combination of flow improvers and fuel heaters (hot-wells)[1] . Since the fall of 1980, the Montreal Imperial Oil refinery has displaced the former -26°C (-15°F) cloud winter diesel with a -18°C (0°F) cloud diesel containing flow improver. Future plans include an expanded use of diesel flow improvers in the Atlantic Region. Experience thus far has been that the flow improved fuel performed as well as the natural product.

Tests on automotive engines presently underway at Kapuskasing by the Co-ordinating Research Council, using three fuels and three different flow improvers are being closely monitored by the principal fuel suppliers.

4.3 Recommendations

In order to obtain some quantitative data on the cold weather performance of the new generation flow improvers, it is recommended that a program of laboratory testing using full scale locomotive fuel system components in a cold weather environmental chamber be developed, to evaluate additive effects on samples of existing summer and winter grade diesel fuels.

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(1) Hot-wells are discussed in Chapter 5.

5. COPING WITH CHANGE IN FUEL PROPERTIES

It is evident that in the short and medium term future, changes to the properties of diesel fuel available to the railways can be expected. Cetane number, distillation end-point and cloud point are the properties most likely to change. Action which may be necessary to avoid disruption to railway operations as the result of such changes is discussed in the following.

5.1 Cetane Number

The current CP and CN specifications for diesel engine fuel call for a cetane number of 40. While it seems quite certain that there will be increasing difficulty in meeting this requirement, no figure lower than 35 was mentioned seriously by the oil companies, and Hycarb does not forecast it dropping below 38 or 39.

It is not expected that a reduction to 35 would have an adverse effect on normal engine operation. The cetane number of the Suncor gas oil sidestream purchased by the railways for use as diesel fuel is around 35 - perhaps somewhat less. Canadian railway locomotives have now been operated on that fuel for about 7 years and that experience has established that the engine bearings can accept the rate of cylinder pressure rise which results from the lower cetane number. Engine maintenance costs have not been unfavourably affected.

As is discussed in Section 5.3, the sidestream fuel is blended with conventional fuel during the winter and consequently, low temperature experience with a 35 number cetane fuel is not as extensive as it would

otherwise be. However, engine starting should not be a problem since locomotive engines are not often shut down in low ambient temperatures. At 35 cetane number there should be little effect on engine efficiency or power output, except perhaps for an increased idle fuel consumption at low water jacket temperatures, and some increase in emissions of unburnt hydrocarbons at idle.

Experiments within the SwRI program, using their 12-cylinder EMD645E3 turbocharged diesel locomotive test engine, showed that only slight knocking occurred when operated on a 30.8 cetane number fuel. In addition, there were no significant penalties in engine power output, brake specific fuel consumption and thermal efficiency(1).

Cetane number can be improved through the use of organic nitrates. The Hycarb report notes that "The effectiveness of organic nitrates is dependent upon the stock, and use has been on an individual refinery basis". Although increased use of such improvers is not desirable from a cost standpoint, some increase in cetane number, if necessary, might be obtainable through their greater use.

5.2 Distillation End-Point

The railways' specifications currently call for a maximum end-point of 350°C (662°F) for winter fuel and 370°C (698°F) for summer fuel. However it has seldom been necessary to accept fuel with an end-point as high as 370°C. Consideration of price and supply may well lead to the production of a separate fuel with such an end-point for railway diesel

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(1) See Appendix A.

engines. As has already been noted in Chapter 3, Suncor were examining the possibility of increasing the end-point of their diesel fuel product to 371°C (700°F), or even to 399°C (750°F) in order to raise production levels.

The major effect on the engine, of an increase in distillation end-point beyond current limits would be to increase engine deposits and emissions. There would probably be little change if the end-point were raised to 371°C (700°F), but engine maintenance would almost certainly be increased if fuel with an end-point of 399°C (750°F) were used with no other change.

The effects on engine deposits could be alleviated by the use of a lubricating oil having an increased additive level. Some experimentation would be necessary to ensure that no other combustion properties had been adversely affected. The increased engine exhaust emissions that would result might require a relaxing of pollution regulations, or at least a stay on more restrictive changes.

The likelihood of having to accept an end-point of 399°C (750°F) at least in the near future does not appear great. Of the oil companies supplying regular diesel fuel, only one suggested such a possibility, and then only in the longer term future which they defined as "10 years hence, or more" (1). However, some increase will no doubt occur.

5.3 Cloud Point

The formation of wax crystals does not affect engine performance provided that the crystals do not block the fuel filters. Indeed, the

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(1) Appendix C - Table 5

wax-forming fraction of the fuel has good combustion properties. However, if the engine fuel filters become blocked the engine will shut down due to lack of fuel.

The use of "hot-wells" in the engine fuel system, a change which is now being implemented by the major railways in Canada, and the availability of third generation flow improvers, should permit the successful use of fuel having a natural cloud point temperature higher than that of current winter grade fuel, possibly even up to the level of current summer grade.

Hot Wells

The railway diesel engine is supplied with fuel by a circulating pump having a greater capacity than the engine fuel consumption at full load. There is, therefore, a surplus of fuel which after passing through the injector supply line is returned to the fuel tank. Inasmuch as the circulating pump runs at constant speed, the amount of surplus fuel returned to the tank increases at lower throttle settings and at idle is, in fact, almost equal to the output of the circulating pump.

For many years locomotives have had a water/fuel heat exchanger piped in the fuel line between the circulating pump and the fuel filters. The fuel was therefore heated by engine cooling water on its way to the filters and thence to the engine. The fuel was further heated in its passage through the injector supply line before the surplus was returned to the fuel tank. The temperature of the fuel in the tank was therefore gradually raised.

In practice, filter blockage sometimes occurred shortly after refuelling if the temperature of the new fuel was below the cloud point, because the fuel had insufficient time in the heat exchanger for wax crystals to pass back into solution and they were collected on the fuel filter.

In a recent development a small chamber, or "hot-well", is installed so that the fuel must pass through it en route to the engine filters. The circulating pump draws fuel from the hot-well and surplus heated fuel from the engine is returned to the hot-well. Cold fuel from the main body of the tank flows into the hot-well at a rate equal to the engine fuel consumption at the prevailing throttle setting. The fuel in the hot-well is therefore maintained at a temperature substantially higher than that in the main tank and the hot fuel has sufficient dwell time to allow wax crystals to pass back into solution before reaching the filters. Temperature regulating by-pass valves are used to limit the maximum fuel temperature at higher ambient temperatures.

New locomotives are now received with hot-wells applied by the locomotive builder and both major railways have modification programs underway to retrofit them to existing locomotives. The cost of the modification is in the order of $3,000 to $4,500 per locomotive. Conversion of the fleets must be completed prior to the time that it becomes necessary to accept fuel with a substantially increased cloud point.

It is expected that for normal operation, the hot-wells alone would be sufficient. The flow improvers will ensure the ability to restart an

engine shut down and drained in service, without the need for first warming up in a shop with consequent excessive delay.

Hot-wells will also facilitate the full use of the gas oil sidestream fuel purchased from Suncor. The cloud point of that fuel as produced at Fort MacMurray is exceptionally low, but unfortunately the fuel picks up wax in transit to Edmonton from material deposited in the pipeline from other products of the plant. This has resulted in the necessity to blend the sidestream with conventional fuel, during winter months. It is expected that the application of hot-wells to the locomotives will allow unblended use of the sidestream.

Fuel Handling and Storage

If the pour and cloud points of future winter grade fuel approach those of summer grade, it will have a major effect on fuel handling and storage practices. Some heating might be necessary to avoid problems at low temperatures. Fortunately, most large refuelling points in major yards receive fuel via road tank wagons from adjacent refineries and it is not expected that problems will be experienced in their unloading. Points which are more remote are supplied by railway tank cars and at such locations it might be necessary to use heated cars and accept the consequent delay in unloading.

It is expected that the use of flow improvers will obviate the necessity for suction heaters inside the main storage tanks. However, it will probably be necessary to provide heated lines to the fuelling stands, especially where these are at a considerable distance from the tanks and/or there are appreciable intervals between the fuelling of locomotives.

The costs of these provisions cannot be readily estimated because of the large number and variety of installations. They will, however, be appreciable and will have to be taken into account in determining the impact of using "off-specification" fuels. Railway management will no doubt wish to establish the magnitude and timing of these costs as part of their normal budgetary and work-planning process.

5.4 Transportation and Storage of Synthetic Fuel

In Chapter 3, reference was made to the suggestion in the Hycarb report of the potential for the railways to obtain additional synthetic fuel from future tar sands developments. Although the net result of a realization of that potential would unquestionably be to the railways' benefit, there are at least two possible liabilities which should be recognized:

(i) Some difficulty might arise in the economic movement of those fuels to points as far east as Winnipeg and beyond. It might depend on the use of the finished products pipeline or on measures to avoid contamination in the crude oil pipeline.

(ii) An increased use of tar sands fuel would increase the need for assurance of alternate supplies, including the possible storage of large reserves to protect against prolonged closure of the tar sands plant.

5.5 Summary

It is not expected that the necessity to operate with a 35 cetane number fuel would have an adverse affect on normal engine operation or on engine maintenance costs. Engine maintenance cost would almost certainly increase if fuel with a distillation end-point as high as 399°C (750°F) were used with no other change.

Some increase in engine maintenance will be necessary as distillation end-point increases. Engine exhaust emissions will also increase.

To cope with anticipated increase in the pour point and cloud point temperatures of railway diesel fuel, the use of hot-wells installed in the engine fuel system will be necessary, along with the increased use of flow-improvers. Additionally, the use of heated railway tank cars for delivery of diesel fuel to wayside storage tanks at remote locations and the heating of lines from fuel storage tanks to the fuelling stands will probably be necessary.

Appreciable costs will be encountered for the installation of hot-wells, and for the provision of heating at wayside fuel storage tanks. As is discussed at the conclusion of Chapter 2, the use of hot-wells will eliminate the necessity for use of alcohol as a de-icer.

6. ALTERNATE FUELS

6.1 Off-Specification Fuel

As has been discussed in Chapter 3, Canada's major oil companies predict that providing there is no major disruption in the supply of refinery feedstock and no serious interruptions to refinery operations, sufficient quantities of diesel fuel to the railways' current specifications will be available to the railways for the next two to three years. It is apparent though, that by that time and possibly earlier, the railways will be forced to accept fuel having a lower cetane number, a higher cloud point and higher distillation end-point than is permitted by current specifications. Action necessary to enable the railways to live with such an off-specification fuel has been outlined in Chapter 5.

As has already been noted, the use of off-specification fuels in railway diesel locomotive engines is being explored in a program of research which has been underway for some time at the Southwest Research Institute in San Antonio, Texas. The status of that program is reviewed in Appendix A of this report.

There are a number of alternate fuels which are possible candidates for use in the railway diesel engine. The gas oil sidestream produced by the Oil Sands Division of Suncor is in fact an alternate fuel and, as already noted, the approximately 1.7 million bbls per year produced represents about 10% of the total current railway diesel fuel usage in Canada.

6.2 Other Alternate Fuels

Certain gases, alcohols, coal derived liquids and coal slurries

represent potential alternate fuels for the diesel engine, at least theoretically. However, much remains to be done before any of these could be utilized successfully for railway diesels.

Gases

Because of their poor ignition quality, hydrogen, propane and methane are not useable in the conventional compression-ignition diesel engine without major modification. Spark ignition would be necessary, or alternatively, a dual fuel system requiring an additional fuel pump and injector for introducing a pilot charge of high cetane number fuel into the combustion chamber to provide ignition. The non-diesel fuel would be injected through a modified injection system. Other retrofitting would be necessary, including modification of the compression ratio and of both on-board and wayside fuel storage systems. Lower power output would result and larger storage tanks would be needed.

Such changes have been proven feasible for stationary diesel engine applications but so far at least, not for engines used in transportation service.

The feasibility of propane as a substitute for gasoline in motor vehicles is already established. Currently there are surplus quantities of propane in the West and in Ontario. Action by government to encourage the use of propane as a highway fuel to relieve pressure on liquid fuels would appear more logical than pursuit of research to investigate its feasibility as a railway diesel engine fuel in the face of the evident penalties as noted above.

The matter of hydrogen as a transport fuel is treated in the Energy Mines and Resources Canada "Discussion Paper on Liquid Fuel Options 1980" Report EP 80-2E. The treatment is brief and is quoted in its entirety in the following:

"The use of hydrogen in engines has been demonstrated around the world, and continues to capture the imagination of both scientists and laymen as the perfect or "ultimate" fuel. Hydrogen might eventually assume this auspicious identity, but probably not for many decades to come. There are three practical problems that impede the use of hydrogen as a transport fuel in this century, except possibly in the premium jet fuel market where its exceptionally high energy-to-weight ratio gives it an advantage on aircraft. The first problem with hydrogen is its very high cost of production, whether from natural gas, coal or the electrolysis of water. The major reason for the high cost is poor conversion efficiency. The energy in the hydrogen is much less than the energy in the feedstock. The second problem is distribution and storage. Compared to natural gas, which is already distributed in Canada and which can be stored on vehicles with modest penalties for tank weight and vehicle range, hydrogen is at a substantial disadvantage.

"The third problem for hydrogen fuel is that it may have more value as a feedstock for upgrading other energy resources to liquid form than as a fuel itself. Hydrogen is the key energy input in synthetic fuels manufacture and upgrading and the cost of most new fuel options depends critically upon how the hydrogen is produced and how effectively it is used. Indeed, most of the new fuels discussed in this paper represent ways to store and carry hydrogen energy in chemical combination with carbon, ways that are more energy-efficient than the hydrogen storage technology developed to date."

These problems with hydrogen as a transport fuel added to the retrofit problems identified earlier in this section, suggest strongly that costly research into the use of hydrogen by the railways as a substitute for diesel fuel does not offer high potential.

Alcohols

As with gases, the poor ignition quality of alcohols makes them incompatible with the compression-ignition cycle of the railway diesel engine. T. N. Pratt of the Electro-Motive Division of General Motors

Corporation, in his paper Alternate Fuel Requirements for Medium Speed Diesel Engines[1], notes that short of the spark ignition approach, the following methods can be considered to promote the ignition process:

(i) Burning of the alcohol as a mixture, or blend, with another fuel of appropriate ignition quality (cetane number)

(ii) Separately introducing the alcohol into the combustion chamber (by carburetion or dual injection) to be mixed and burned with a pilot charge.

(iii) Burning the alcohol as an emulsion by utilizing a suitable device to produce a homogeneous product with another fuel of high ignition quality just prior to injection.

Thus alcohols rely on a primary fuel of good ignition quality for railway service. They are essentially fuel extenders.

As part of the SwRI research and investigations into the use of alternate fuels, engine testing has been carried out with both ethanol and methanol as a fuel using each of the three above-listed methods (Appendix A). The engine used was their two-cylinder Roots-blown EMD567 test engine. Problems of engine knock and thermal efficiency were experienced.

It was concluded for several reasons, including their high cost, that stabilized emulsions do not constitute a satisfactory fuel. Unstabilized emulsions, which do not incur the expense of the chemical stabilizer, are more favourable, but require the addition of a mechanical emulsifying system to the engine and separate alcohol and diesel fuel storage. In the case of the other methods for burning alcohol, however, it is believed by the researchers that the problems encountered could be overcome for that particular laboratory engine. They note however, that "Work performed to

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(1) Presented at the 7th Energy Technology Conference & Exposition, Washington, D.C., March 1980.

date here has not addressed the problem of making conversions suitable for use in the field and of minimizing any adverse, long term, fuel-related effects arising from prolonged engine operation on those fuels".(1)

With respect to operation on alcohols, Pratt notes the problems of gum formation, the fire and explosion hazard associated with alcohols, the corrosive effect on certain metals, plastics and elastomerics with the consequent need for increased attention to fuel systems, and other concerns, and concludes that "the adaptation of alcohols to medium speed diesel engines is bound to the use of two fuels and imposes major implications relative to the aspects of storage, handling and retrofit."

Coal Derived Liquids

Although several processes for the production of liquid fuel from coal are known, and although Canada has vast coal reserves, there has as yet been no start on production in Canada. The earlier referenced Energy Mines and Resources discussion paper notes that "A version of this process (The South African process) could be adapted to Canada's coal resources and fuel needs, and could provide us with 30 Mb/d of transport fuels as early as 1986, perhaps twice as much by 1990. This process is only about 40% energy-efficient at this time and the fuels would be quite expensive. Product cost estimates occupy a broad range, from $45 to $65 a barrel oil equivalent (1980 dollars) depending upon factors such as plant location, coal quality and market for by-products".

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(1) Appendix A

Under these circumstances, a program of investigation by the railways at this time, into the use of coal derived liquids as a substitute for diesel oil, is not justified, notwithstanding the fact that operation of their two-cylinder engine on a synthetic coal-derived fuel was accomplished by SwRI (Appendix A).

Coal Slurries

Coal slurries appear to offer little early hope as a realistic alternative to diesel fuel. As noted by Pratt, problems include detrimental effect on injection equipment and engine component wear. Poor ignition qualities would result in increased engine deposits and emissions, necessitating major engine modifications to minimize these effects. The storage stability of the slurry in the absence of special emulsifiers and/or continuous mixing and in fact, control of the slurry proportions, would necessitate special care. Maintenance intervals would be shortened by the use of such fuels, due to their degrading effect on the engine lubricant and filtration system.

6.3 Railway Electrification

Electrification is an additional alternative to the present reliance on diesel fuel. Although for Canadian railways, resolution of certain technical and operational questions is necessary before implementation would be possible, it is probable that should the necessity arise, these could be resolved more quickly and certainly than most of the uncertainties associated with alternative on-board fuels. Electrification, as an alternative, has the advantage that the major problems are known now,

and technology and operational experience from elsewhere in the world is available to assist in their resolution.

Electrification, however, is very costly to implement and freedom to adopt this option is thus restricted by economic considerations. Financial benefits are generated principally through savings for locomotive fuel and maintenance, but high traffic levels are needed to generate the savings required to justify the large capital investment. Additionally, there are problems with financing due to the very high initial investment needed before benefits can commence. Thus, although possibly economically viable from the standpoint of the nation as a whole, electrification does not appear to be a commercial possibility for the railways at this time.

6.4 Conclusions

The rapidly escalating cost of conventional diesel oil combined with the apparent certainty of decline in its quality in two to three years, is not an encouraging prospect for Canada's railways. Although the federal government continues to hold out the expectation of Canadian self-sufficiency in oil by sometime in the 1990's, it seems evident that the situation will worsen before it improves. The cost of diesel oil will continue to increase. Growth in the supply of synthetic fuel from the tar sands could provide some relief from the standpoint of supply, but not from the standpoint of cost. None of the alternative on-board fuel options are operationally feasible at this time nor is it likely that their cost would be lower even if operational feasibility were to be established. The very high capital requirement and delayed return on

investment rule out immediate steps towards electrified operation.

Adaption to the use of off-specification diesel fuel is the railways' only realistic choice at this time. Close contact with the SwRI research program should be maintained in order to obtain the maximum possible benefit from that work. The economics of electrification should be monitored on a regular basis as diesel fuel costs and traffic levels increase.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

(i) Providing there is no major interruption to the supply of refinery feedstock and no serious interruption to refining operations, there will be sufficient quantities of diesel fuel to current quality available to Canadian railways for the next two to three years.

(ii) In the longer term however, important properties of the fuel supplied, principally cetane number, cloud point and distillation end-point will change.

(iii) Canadian railways can cope with the changes to diesel fuel properties that are likely to occur over the next five to ten years, without significant losses in operating effectiveness.

(iv) Implementation of the oil industry's planned refinery expansion program in the West is of critical importance in ensuring adequate supplies of fuel and keeping quality within manageable limits.

(v) None of the potential alternate on-board fuels (gases, alcohols, coal derived liquids or coal slurries) constitute technically viable alternatives to off-specification diesel fuel at this time. Electrification is not a commercial possibility at this time.

(vi) Due to the anticipated increase in the pour point and cloud point temperatures of railway diesel fuel, the use of hot-wells

installed in the engine fuel system will be necessary, along with the increased use of flow improvers. Additionally, the use of heated railway cars for delivery of diesel fuel to wayside storage tanks at remote locations and the heating of lines from fuel storage tanks to the fuelling stands will possibly be necessary. Appreciable costs will be accrued to implement these changes.

(vii) New flow improvers now under development will enable a significant extension of the lower operable temperature of diesel fuel.

(viii) Future tar sands developments and heavy oil upgrading plants may offer a potential for the railways to obtain additional low quality diesel fractions, perhaps similar to the gas oil sidestream already being produced by Suncor.

7.2 Recommendations

The railways should:

(i) maintain close contact with the SwRI research program on the use of alternative fuels for railway diesel engines.

(ii) discuss with the planners of future tar sands developments and with Syncrude, the possibility of obtaining additional low quality diesel fractions, perhaps similar to the Suncor gas oil sidestream.

(iii) continue with their program of installation of hot-wells in locomotives.

(iv) maintain contact with those researchers conducting the flow improver tests on automotive engines at Kapuskasing.

(v) commence development of plans for a program of laboratory testing using full scale locomotive fuel system components in a cold weather environmental chamber, to evaluate effects of the new flow improvers on existing summer and winter grade railway diesel fuel.

(vi) commence the development of methods and costs for heating of lines from wayside fuel storage tanks to the fuelling stands.

(vii) review the economics of conversion to electrified operation as diesel fuel costs and traffic levels increase.

APPENDIX A

Status of the Southwest Research Institute's Investigation of Alternative Fuels for Medium Speed Diesel Engines

Background

The work being carried out by the Southwest Research Institute (SwRI) is part of a comprehensive project titled "Alternative Fuels for Medium Speed Diesel Engines" (AFFMSDE) being carried out in the United States. The support for this project has come from both government agencies and industry in the form of direct financial contributions, equipment and services-in-kind. Major supporters include the U.S. Department of Energy and the Association of American Railroads.

The overall objectives of the AFFMSDE project are:

1. To identify problems, and to develop technical approaches to the solution of those problems, associated with the operation of medium speed diesel engines on alternative fuels such as:
    - "Off-Specification" fuels, when the base fuel is diesel #2, derived from petroleum
    - Fuels derived from coal, oil-shale and tar-sands
    - Fuels the use of which may be required because of a lack of adequate supply of fuels from petroleum, coal, oil-shale and tar-sands resources.
    - Alternative fuels the use of which may be required because of unpredictable failures in supply, i.e. "contingency" and/or "emergency" fuel forms.
2. To identify the nature of, and quantify to the extent appropriate and practical, the problems of conversion of equipment, transition to and continuous operation on alternative fuel forms as they would be encountered by rail and marine equipment manufacturers and business organizations operating in the transportation industry.
3. To effectively disseminate the information resulting from these activities to the appropriate persons in the involved industries.

The SwRI work is currently concerned with defining the ability of the medium-speed engine to operate on certain alternate fuels and to define

performance characteristics of the engine under such operation. The U.S. Federal Railroad Administration is a major supporter of the SwRI Alternate Fuels research program, along with the U.S. Department of Energy and the Association of American Railroads.

Status

The September 8, 1980, issue of the widely read magazine Railway Age, published by the Simmons-Boardman Publishing Corporation, contains an excellent article on the SwRI program. The article is endorsed by the SwRI research team and is reproduced in its entirety in the following pages with the kind permission of the publishers.

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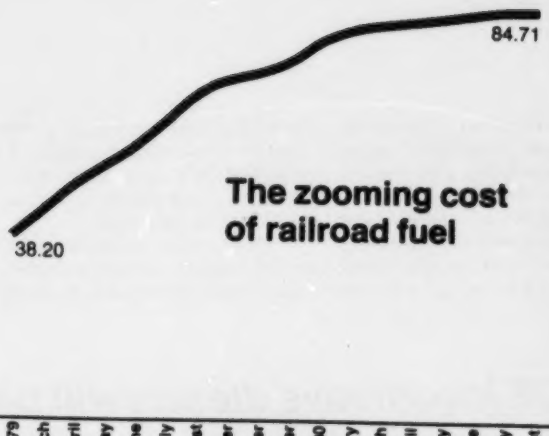
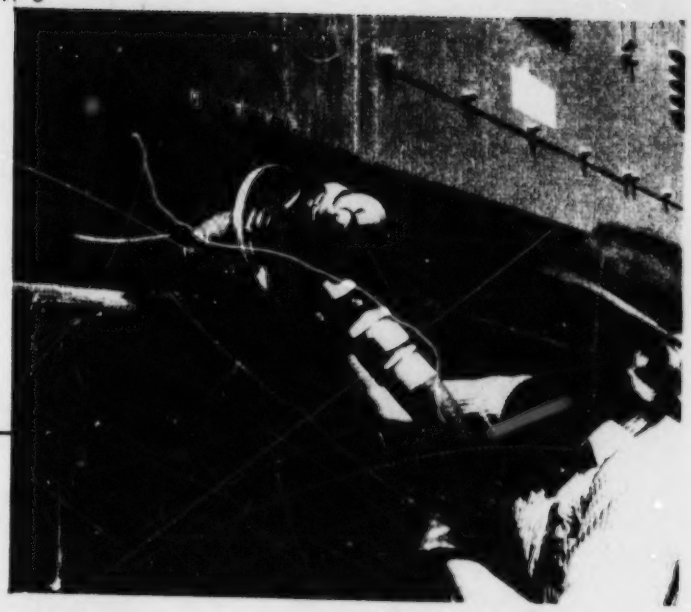


The zooming cost of railroad fuel

Source: January 1, 1979 from "Indexes of Railroad Material Prices and Wage Rates, Series QMPW; other dates from verified statements of carriers submitted in Ex Parte 311, August 11, 1980 (rev.)



The search for alternative diesel fuels

Can the basic diesel-electric engine be modified to burn something other than "pure" diesel fuel? Southwest Research Institute at San Antonio, Tex., is looking for the answer.

By GUS WELTY, Senior Editor

Diesel fuel: Last year, U.S. railroads consumed 4.1 billion gallons of it. They paid an average of 54 cents a gallon for it, which works out to more than $2.2 billion. By the end of 1979, however, the average price had risen to 76 cents a gallon, and as of a month ago, Aug. 4, 1980, it stood at 84.71 cents—a price which, at 1979 consumption levels, comes to a staggering $3.47 billion on an annual basis.

At this point, fuel supplies are adequate, but nobody sees prices coming down (to any significant degree), and there are far more pessimists than optimists regarding future fuel availability.

Conservation, of course, is one approach to the problem: Don't let locomotives idle when they can be shut down; equip fueling stations with no-spill systems; install fuel-saving units on locomotives so that power can be turned off when it's not needed; and match power more closely to tonnage. Railroads are doing all of these things.

Electrification is another possibility, but at costs of $1 million a mile (and climbing) for installation plus the costs of re-equipping the locomotive fleet, it remains just a possibility. The Federal Railroad Administration is interested, and a few railroads are interested—but as yet nobody has come up with the money, so at best, the next 10 critical years will see little electrification.

● **Burn something else?** How, then, about the use of alternative fuels? How about keeping the basic diesel-electric locomotive, but modifying its engine as required to burn something besides "pure" diesel fuel? This is what Southwest Research Institute in San Antonio has been working on since August 1978, when a cooperative research program was begun by the U.S. Department of Energy, FRA, and the AAR to investigate the use of alternative fuels for medium-speed diesel engines, the class of engines (with maximum rpm of between 800 and 1,200) existing in locomotives, in inland-waterways and intercoastal vessels, and on offshore drilling rigs.

SwRI undertook the program with three objectives: (1) to identify the problems associated with operation of medium-speed diesels on a broad range of alternative fuels and to develop technical approaches toward the solution of these problems; (2) to identify the problems of conversion of existing equipment to use alternative fuels as those problems are encountered by manufacturers and users; and (3) to spread the word about the information developed, so that all concerned might be able to take advantage of it.

Underlying the program is, of course, the present dependency of vital transport agencies upon an adequate supply of diesel fuel (usually of No. 2 specification). As SwRI points out, the supply and pricing of such fuel oil is significantly influenced by the actions of foreign oil producers, and for railroads (and others) "the consequences of high fuel prices and/or a restriction on the amount of fuel available are both obvious and ominous." On the other hand, while reduction in fuel prices may be "a forlorn hope," there are in fact several ways that the amount of fuel available to operate diesel engines can be increased.

● **Save, extend, or substitute.** John O. Storment is manager-engine research and development in SwRI's Department of Engine and Vehicle Research, Automotive Research Division, and he makes these observations:

"First, if a fuel specification such as

cetane number, viscosity, boiling range, or sulfur content could be relaxed or broadened, then the steps in the refining process could be reduced. A reduction in the number of refining steps would reduce the energy consumption and increase the efficiency of the refining process, and a finished engine fuel could be produced in greater quantities than No. 2-specification fuel. Of course, acceptable engine performance and durability with the off-spec diesel fuel must be obtained.

"Second, supplies of diesel fuel, whether of No. 2 or some other specification, can be extended if another combustible material can be mixed with the diesel fuel and the resulting 'hybrid' fuel used in conventional engines. Examples of hybrid fuels are mixtures of alcohol and diesel fuel and mixtures of small carbon particles and diesel fuel.

"Third, with suitable modification, diesel engines can be operated on non-diesel liquid fuels such as alcohol or on

At SwRI, full-sized EMD and GE locomotive diesels will be used

Southwest Research Institute's fuels research program will be built around its existing EMD two-cylinder 567 research engine and two full-size power plants, the 12-cylinder turbocharged EMD 645 E3 and GE 7FDL. These big engines and related hardware have been furnished by the AAR with the cooperation of several of its member roads, and further support has come from the Railway Progress Institute and its members, importantly including EMD, GE, and Morrison-Knudsen. For its part, SwRI is providing the lab building, along with all support equipment and instrumentation, and paying for engines and other hardware.

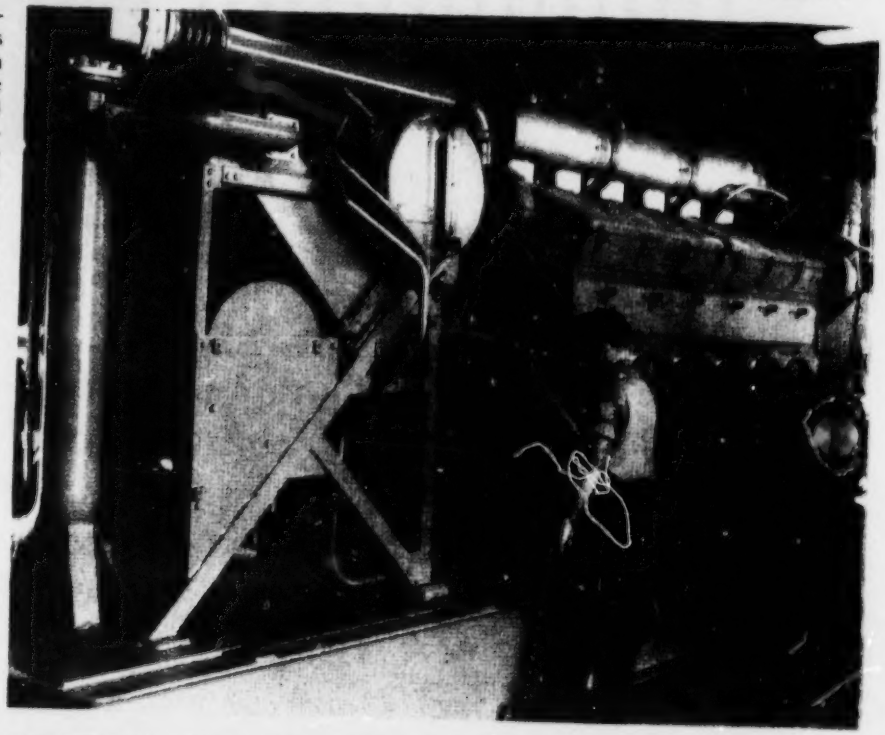
In setting up the installation—which is now better than 80% complete—SwRI installed special support systems for fuel supply, engine cooling, and power absorption.

Five underground fuel tanks, ranging in size from 1,000- to 10,000-gallon capacity, are in place and connected by a patch panel so that fuel may be pumped to or from any combination of tanks. This flexibility will allow the type of fuel supplied to an engine to be changed while the engine is running and will also permit simple fuel blends to be concocted (with more extensive fuel-blending capability available at the institute if it is needed).

Engine cooling is provided by six GE locomotive radiators mounted in a specially constructed stand, along with a constant-speed, variable-pitch turbine fan, with pitch controlled automatically according to coolant temperature. In addition, each engine is equipped with its own thermostats to minimize warm-up time and maintain coolant temperature during low-power operation.

Power absorption for the EMD dc generator and the GE dc-rectified alternator is accomplished through use of two Alco locomotive load grids equipped with a cooling fan for heat dissipation. The design of the cooling and power absorption systems will permit operation of only one engine at a time, but this isn't regarded as a handicap.

At one end of the lab building, SwRI has constructed a sound-insulated control



room to contain readouts and recording devices for engine performance parameters such as speed, generator output, fuel consumption rate, temperatures, pressures, and exhaust smoke density; complete gaseous emissions instrumentation for measurement of unburned hydrocarbons, oxides of nitrogen, and carbon monoxide has also been provided.

Transducers will be installed to obtain continuous cylinder pressure data, and injectors in each engine will be suitably instrumented for data on injection timing and duration. All instrumentation and transducers will be interfaced with a computer-based, high-speed data-acquisition system, which will allow the needed engineering calculations to be performed on the data with later graphic and tabular display on a crt screen and/or in hard-copy form.

Engine start-up and check-out of the installation is scheduled for late September, after which baselining of the engines on No. 2 diesel fuel will begin. After baseline performance and emissions for No. 2 fuel are determined, the fuel-tolerance envelope for each engine will be established with off-specification fuels: The two fuel series that will be emphasized will feature low cetane number and high viscosity, since work with the two-cylinder engine has indicated that distillation range has much less effect upon the engine than do these two other fuel properties.

Says John Storment: "We're confident that this engine facility will meet the requirements imposed by the alternative-fuels program both now and in the foreseeable future. And, while this program will occupy the engines for the next two years and perhaps beyond that, the facility will ultimately be available for other types of research and development work."

gaseous fuels such as LNG or propane."

● **Search and develop.** SwRI's first-phase research program involves laboratory investigation of the operating characteristics of medium-speed diesels using alternatives, with fuels such as off-spec diesel fuel being investigated first. Results of this work are expected to define the fuel-tolerance envelope of EMD and GE power plants for these off-specification fuels and provide basic information about hardware modifications that may be required for these engines to operate with unconventional fuels such as alcohol and gaseous fuels.

This is, essentially, the research phase of the program. The development phase, Storment says, "will bring the engine hardware and related equipment from the research stage to a state of more advanced design which, in turn, will permit operation of full-sized laboratory engines under simulated locomotive duty cycle conditions. The goal of this development work will be to solve the salient problems of engine operation with the candidate fuels and to obtain acceptable levels of performance, durability, and emissions. Any changes to the locomotive fuel system required by each alternative fuel will also be defined."

Candidate fuels selected for the development phase, Storment says, "will probably cover the spectrum of fuel types. This broad-based approach is designed to provide preliminary information on a wide range of fuels and, therefore, will allow for the uncertainties of fuel availability in the future."

(SwRI's "bench" engine, a two cylinder EMD 567 built by EMD a number of years ago, is serving as a screening device for fuels that may later be used in the 12-cylinder EMD 645 engine that has been installed. No such small-cut engine exists for the GE 7FDL engine that has also been put in place in San Antonio, so for the GE, tests will begin with the big engine.)

● **Options and complications.** In reflecting upon the problems, Storment offers these observations:

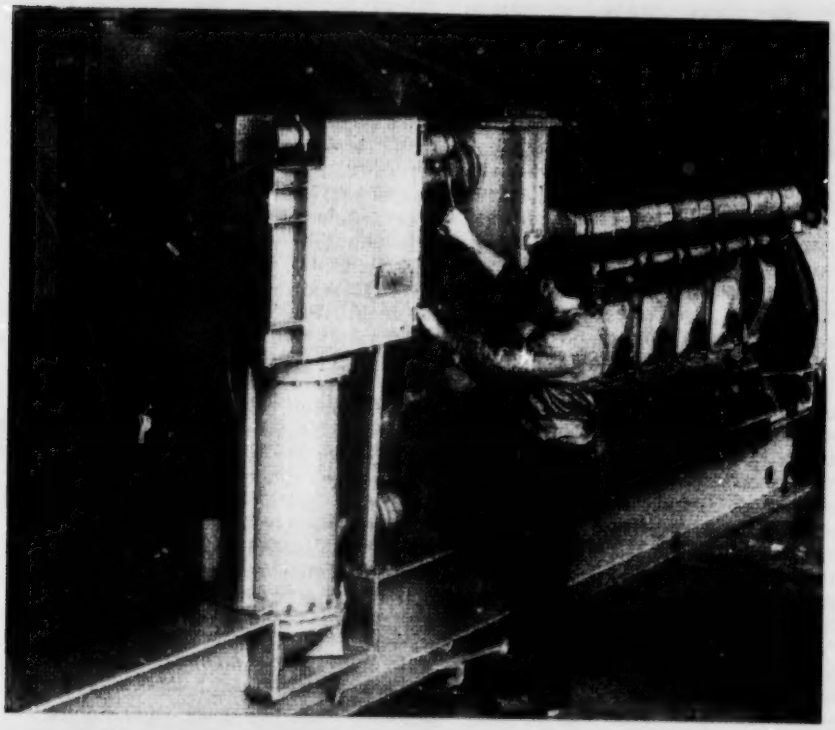
"It would be best if people within government, the fuels industry, and the transportation industries knew which fuel or fuels were going to be available in quantity in the future. The efforts of our program could then be focused on a minimum number of fuel types, perhaps just one, for these medium-speed diesel engines. But such is not the case, and this raises questions.

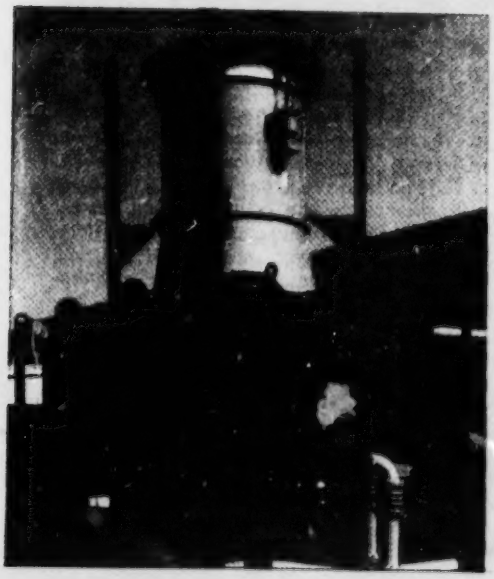
"For instance, will crude oil—whether from conventional petroleum sources or derived from sources such as coal, oil shale, or tar sands—continue to be refined to produce a high-quality diesel fuel such as No. 2, or will a new and lower-quality specification, such as the recently proposed No. 3 fuel, be produced?

"Or, will all crude be converted to a universal-type fuel for both diesel and spark-ignition engines? This so-called broadcut fuel is not yet precisely defined, but it would probably have a cetane number in the range of 20 to 30 and would not be suitable for use in diesel engines in their present configuration.

"No one can yet answer these questions, but production of poor-quality fuels will receive serious consideration because of their potential for a greater yield of finished fuel from a given amount of crude. For example, it is estimated that at least a 5% higher yield can be achieved by

to test alternate fuels





Key equipment in SwRI's fuels research program will be two 12-cylinder, turbocharged locomotive diesel engines—the EMD 645 E3 (above left) and the GE 7FDL—furnished by the AAR and several member roads.

The facility's engine-cooling system consists of six GE locomotive radiators and a turbine fan, with a locomotive load grid system for engine power absorption (in the lower left hand corner).

Researchers are exploring use of diesel-type, hybrid, and unconventional fuels in unmodified and modified engines.

production of a broadcut fuel."

Further, Storment notes, the problem in selecting a specific fuel or even fuel type is complicated by the fact that some transportation companies, especially railroads, have access to their own potential fuel sources, including coal and shale oil deposits: "The final finished fuel available to a railroad with access to these energy sources would be determined by decisions on whether to convert coal to methanol or synthetic crude, and whether to convert synthetic crude to No. 2 fuel oil or to some lower specification. A similar choice as to the finished fuel quality would have to be made in the case of syncrude derived from shale oil. Thus, the solution to the problem of available fuels in the future may not be the same, on an industrywide basis."

● **A broad approach.** For this reason, the researchers are taking a broad approach, which may lead to broad results. For example, they say, the program may produce a definition of a minimum-quality fuel that can be used in engines in their standard configuration, without hardware modifications or other optimization techniques being applied. This fuel would be defined by absolute limiting values of properties such as cetane number, viscosity, distillation range, and sulfur content.

Another task might be to convert the engines to operate on a diesel-type fuel of extremely poor ignition quality, such as solvent-refined, coal-derived fuel or broadcut fuel. Yet another investigation would involve hybrid fuels based upon No. 2 diesel mixed with a fuel extender such as alcohol. The principal effect of the alcohol, SwRI notes, is to degrade the hybrid-fuel cetane number, and the limiting amount of alcohol which can be used should be defined to ensure that the maximum amount of No. 2 is replaced by alcohol.

At the far end of the spectrum, in SwRI's view, lie highly unconventional fuels such as straight alcohol and gaseous fuels, which are unsuitable for use in diesel engines without an ignition source to ignite the fuel in the cylinder. When an ignition source is needed, it could be a spark plug, but in a diesel the simplest method of igniting the main fuel charge is through a pilot injection of a small amount of diesel fuel to initiate combustion.

The foregoing approach does away with the complication of installing an ignition system, Storment says, but if a high degree of utilization of these alternative fuels is desired, with alternatives replacing the maximum amount of diesel fuel, then direct high-pressure injection of the alcohol or gaseous fuel into the cylinders is necessary. Thus, the engine must be extensively modified with the addition of a second injection system so that dual-fuel operation is possible: "The problems are not trivial, but work done several years ago at SwRI for Burlington Northern showed that a two-cylinder EMD 567 laboratory engine could be operated with over 90% of the fuel energy requirement of the engine furnished by methanol. These results have been confirmed in the current program."

What's down the road? As Storment sees it, "if developmental problems are satisfactorily solved for the candidate fuels and assuming that industry interest exists, a field demonstration will be proposed with in-service locomotives powered by the two medium-speed engines of interest. This demonstration phase will permit field operating experience and data to be obtained for a broad variety of alternative fuels."

● **Findings so far.** All of the research work to date has been done using the two-cylinder Roots-blown EMD 567, which is fully instrumented to provide data on speed, power output, injection timing, continuous pressure in one cylinder, and pertinent operating temperatures and pressures. Test results of primary interest, Storment notes, are those involving brake specific fuel consumption (i.e., pounds of fuel consumed per hour per developed or brake horsepower), brake thermal efficiency (the percentage of total fuel energy that is converted to brake horsepower), and brake specific emissions in grams/bhp-hr of unburned hydrocarbons, nitric oxide, and carbon monoxide, along with exhaust smoke density.

SwRI developed an engine test cycle that corresponds to the notched throttle operation of an EMD engine in a line-haul locomotive. Modes of this test cycle are defined by engine speed and fuel consumption, which is set at one-eighth the consumption of a 16-cylinder engine; therefore the test cycle consists of nine modes—eight power-producing conditions plus low-idle condition.

To date, the program has looked at a range of off-spec diesel fuels, a high-quality synthetic diesel fuel, various blends of No. 2 fuel and alcohol, and two nondiesel fuels of very poor ignition quality (methanol and a synthetic coal-derived liquid fuel).

● **Off-specification diesel fuels.** Here, fuel properties were systematically varied as independently of other properties as possible by blending various readily available fuel components. Cetane number, viscosity, and distillation range were varied in this manner, with test results defining the limits of each fuel property for the existing engine configuration; that is, no modifications were made to enhance the engine's tolerance of and performance with the off-spec fuels. In all, eight fuels in the low-cetane series, with cetane values ranging from 55 (for the baseline No. 2 fuel) down to 17, were tested.

For a diesel engine, the limiting fuel cetane number is determined by the amount of knocking (caused by high rates of cylinder pressure rise) that can be tolerated, since the principal effect of an increase in knock level is a decrease in engine durability. Current No. 2 specification fuel, SwRI points out, has a minimum cetane limit of 40, and in the tests with the two-cylinder 567, the cetane number could be reduced to 30-32 before a significant increase in engine knock was observed; in addition, there were no significant penalties in engine power output, brake specific fuel consumption, and thermal efficiency. Below about 30 cetane, however, greatly increased rates of cylinder pressure rise and knocking were observed when the engine was operated below No. 6 throttle position. Higher than normal but still acceptable rates of pressure rise were obtained in throttle positions above No. 6, even when cetane number was reduced to as low as 17 (though, SwRI notes, there would undoubtedly be some decrease in engine durability in such operation).

This determination of the relationship between throttle position and minimum allowable cetane number was judged to be important "since if an emergency situation arose in which only fuels of very low cetane number were available, an attempt could be made to operate engines in the throttle positions for which knocking was minimal, thus minimizing the harmful effect on engine durability of operating on poor quality fuel."

Then, a highly viscous lube stock was heated to produce variations in fuel viscosity; SwRI describes the test this way: "The lube stock was heated by directing water from the engine cooling system through a heat exchanger. This system, which was judged to be the most practical method of heating the fuel for the laboratory engine, limited the maximum fuel temperature to 155°F, which gave a viscosity of 38 centistokes. Test results showed that the engine fuel system was the primary limiting factor in the use of high-viscosity fuel. The fuel filters and the small fuel lines to each injector are the principal obstructions to fuel flow. And as expected, engine operation in the upper throttle notch positions, with their higher required fuel flow rates, was most affected by increases in fuel viscosity. The

limiting viscosity for notch No. 8 was 65 centistokes, while for operation at No. 6 and below a viscosity of 105 centistokes sufficed. No attempt was made to operate the engine with fuel viscosity above 105 centistokes, but it is obvious that even higher viscosities could be tolerated at the lower notch positions.

"As long as viscosity was low enough to allow normal fuel supply requirements to be met, engine power, fuel consumption, thermal efficiency, and combustion pressure characteristics were substantially equivalent to corresponding data obtained with No. 2 fuel. Even under the extreme conditions of 65 centistoke fuel and notch No. 8 engine operation, for instance, brake horsepower and thermal efficiency were only about 10% lower than baseline figures."

While SwRI found that exhaust smoke density was essentially unaffected by reductions in cetane number, use of high-viscosity fuel did produce a slight increase in smoke density.

In the distillation-range tests, SwRI used eight fuel blends and a heavy No. 5 fuel, with the blends produced through various combinations of No. 2 base fuel, heavy lube stock, and unleaded gasoline. As to the properties and compositions of these fuels, SwRI notes that "the so-called 'dumbbell' blends have a preponderance of light molecular components and heavy molecular components; they therefore have very low and very high initial and end points compared to baseline fuel. The two extended-range fuels have normal initial points and very high end points, beyond 1,100°F. It was not possible to alter distillation range without simultaneously changing other important fuel properties such as cetane number and viscosity—a factor that complicated analysis of the engine data obtained during this test series."

Some of the test fuels in this series, SwRI analysts found, "did produce noticeable effects on the measured engine performance and emissions parameters. However, a multivariate statistical analysis of the data indicated that these observed effects were due to changes in cetane number, API gravity, and/or fuel heating value, rather than distillation range per se. The results of this analysis indicate that if distillation range could be broadened significantly while maintaining cetane number and viscosity within the acceptable limits established previously, the resulting fuel would be suitable for the two-cylinder 567 engine. Of course, such a fuel should have adequate values of API gravity and heating value for the engine."

● **Alcohol-diesel fuel mixtures.** In the area of so-called hybrid fuels, engine testing has been completed with both methanol and ethanol mixed with No. 2 specification fuel, the mixtures in the form of unstabilized emulsions of the individual alcohols in the diesel fuel. These emulsions were produced by blending the two fuel components on-line with an emulsifying device located as close to the engine as possible; SwRI emphasizes that separation of the fuel components occurs in one minute or less after mixing, so the mixture must be put into the engine as soon as possible (while any unconsumed return fuel is remixed in the emulsifying device).

The researchers came up with a hybrid fuel characterized mainly by a reduced cetane number, with the degree of reduction proportional to the amount of alcohol in the mixture. The tests determined the amount of alcohol that could be utilized before engine knock was substantially increased: "It was found that the maximum permissible amount of alcohol varies with engine operating condition, that is, throttle notch position. For example, about 12% of the diesel fuel heat energy requirement in notch No. 8 could be replaced with methanol; about 22% could be replaced in the middle notch positions; and almost 30% could be replaced in the lower notch positions. For ethanol, the figures were slightly different, about 22%, 28%, and 32% for the respective notch positions."

The limiting factor here, SwRI says,

SwRI's concern: Will sufficient funds be available to solve the fuel problem?

When it comes to predictions regarding future supply and price of petroleum-based fuels, the pessimists call the optimists dangerously naive, and the optimists call the pessimists apocalyptic.

About all you can do is look at facts, and today's are these: (1) Despite lowered use of petroleum-based fuels, prices haven't gone down; (2) reserves are being depleted faster than new supplies are being found; and (3) foreign sources of oil are and will continue to be undependable.

John O. Stormont

With that as backdrop, what's happening at Southwest Research Institute takes on additional importance.

SwRI is not one of the old, traditional research-tanks, and it's Swri, not SRI, mainly because SRI would be confused with the folks at Stanford. SwRI began operations just 33 years ago, as an independent, nonprofit corporation doing applied research, development, and testing work under the sponsorship of business, government, and even individuals. It employs a staff of almost 2,000 persons, its budget exceeds $72 million, and its researchers are hoping they can do a good piece of work on alternative fuels for medium-speed (i.e., railroad and marine) diesel engines.

SwRI has already done a lot of preliminary research, and it now has the tools to do a full-scale research job. What it needs are the funding commitments to allow that job to go forward at the pace that it should—and those commitments remain chancy.

Sponsorship came first from the U.S. Department of Energy's Office of Transportation Programs, and that put the program in business back in August 1978. Significant funding was later obtained from the Federal Railroad Administration's Office of Research and Development. AAR and its member roads have helped, mainly in providing full-size engines for test, and out of funding expected for fiscal year [illegible] AAR's Research and Test Department.

At this point in the program, [illegible] John Stormont says it's our clearly [illegible] principal concern of SwRI is whether sufficient funding will be available over the next several years to make significant headway in solving the alternative fuels problem for the railroads. The problem of obtaining adequate funding is, we think, primarily related to convincing interested parties of the pertinency and timeliness of this program and of the need to solve the salient technical problems at the earliest possible moment."

"A concerted effort to widen the fuel tolerance of the locomotive diesel engine seems to be minimum insurance."

"was engine knock level: No other significant penalties in engine performance were observed. However, it should be noted that the use of an alcohol-diesel fuel mixture requires use of larger-capacity fuel injectors if it is desired that the engine develop its normal power output in the top two or three notch positions. This is because the mixture has a lower heat energy content per unit volume than does diesel fuel; consequently, a larger quantity of the hybrid fuel must be injected per engine cycle in order to develop normal power output. For the 567 test engine, this was accomplished by substituting the next larger-size 567 injectors for the injectors normally used. No problems were encountered with the unit injectors while operating on the alcohol-diesel fuel emulsions, and as in the previous test series, no attempt was made to optimize engine performance for operating on these hybrid fuels."

● **Synthetic diesel fuel.** In these tests, SwRI says, the engine "was operated on a marine diesel fuel produced from synthetic crude obtained by the PARAHO shale oil process. This was a very good grade of fuel, which essentially met No. 2 specification, and so it was tested with the engine in standard configuration. As expected, all aspects of engine performance were completely acceptable and comparable to those obtained with the baseline No. 2 diesel fuel."

● **Dual-fuel engine operation.** In order to conduct tests with both straight methanol and the synthetic coal-derived fuel SRC II (with cetane numbers of about 7 and 16, respectively), it was necessary to convert the engine to a dual-fuel configuration and use pilot injection of diesel fuel, a conversion that involved installation of two engine-driven, single-cylinder injection pumps at the rear of the generator and a small-diameter, pencil-type injector in the pressure-relief port in each cylinder head. These auxiliary pumps and injectors were then used to inject pilot diesel fuel, while the main fuel—methanol or SRC II—was introduced through the usual EMD unit injectors, and a limited engine performance optimization effort was conducted in which the effects of pilot diesel injection timing, main injection timing, and the ratio of main fuel to pilot fuel were determined.

Use of methanol as the main engine fuel "posed some additional problems which were not encountered with any of the diesel-type fuels," and SwRI sums them up this way:

"First, the very poor lubricating properties of methanol required that a system be developed to lubricate the EMD unit injectors with a small amount of diesel fuel. About 4% by volume diesel fuel was mixed with methanol in the fuel line leading to each injector. This system prevented excessive wear in the injectors over a period of about 30 hours of testing. Second, the heat of combustion per unit volume of methanol is only 44% of that of No. 2 diesel fuel. Therefore, about 2.3 times as much methanol as diesel fuel must be injected to obtain an equivalent heat energy input. To accomplish this, the standard 567 injectors were replaced with higher-output versions used with the turbocharged 645 engine, but even the larger injectors did not deliver the amount of methanol required for operation in notches 7 and 8."

Still larger injectors are available on special order, SwRI says, but time didn't permit the exercise of that option, so, because of the restricted power output in notches 7 and 8, most of the testing was done at notch 6. There, "it was possible to find conditions of pilot-fuel injection timing and methanol injection timing that allowed over 80% of the fuel energy requirement to be provided by methanol, with horsepower and thermal efficiency values equal to or slightly better than corresponding baseline diesel fuel values. Some roughness in engine operation and a moderate increase in engine knock level were noted during these tests; however, it is believed that further optimization of injection parameters will overcome these problems. And, as might be expected with engine operation on methanol, exhaust smoke was greatly reduced."

Tests with SRC II fuel were run in a similar fashion, but here it was not necessary to use oversize injectors (since the heating value of this fuel is about equal to that of No. 2 fuel), nor was it necessary to furnish additional lubrication to the injectors. In this series, researchers found that "under optimum conditions, 90% to 95% of the fuel energy requirements could be furnished with SRC II. Under these conditions, brake horsepower and thermal efficiency were essentially equal to baseline values for notch 8 operation. Some roughness in engine operation and knocking were present in lower notch positions, but smooth operation was obtained above notch 6. Exhaust smoke levels were about equal to baseline."

A comprehensive report on the test work involving off-specification diesel fuels and dual-fuel operation with methanol and pilot diesel fuel will be available later this year, and it is expected that the findings will be distributed by the AAR to member roads; a similar report covering work with the alcohol-diesel fuel mixtures and the two synthetic fuels will be available by next summer.

● **Conclusions.** As the program is about ready to move from testing on the two-cylinder research engine to testing on the full-size EMD and GE power plants, Storment assesses the situation this way:

"The results obtained thus far are encouraging. In its standard configuration and without modification, the research engine is tolerant of a wide range of fuel specifications for diesel fuels and also of hybrid fuels based on mixtures of No. 2 diesel and alcohol. For fuels of extremely poor ignition quality, such as straight methanol and the synthetic fuel SRC II, it is possible to replace 80% to 90% of the diesel fuel energy requirement with the alternate main fuel. A limited amount of optimization of injection parameters for the dual-fuel system yielded excellent results, although it is evident that much work remains to be done in this area.

"However, a word of caution: These results are, at this time, applicable only to this particular laboratory engine. Work performed to date here has not addressed the problem of making conversions suitable for use in the field and of minimizing any adverse, long-term, fuel-related effects arising from prolonged engine operation on these fuels. These aspects of alternative fuel use in locomotives, along with the locomotive system modifications which might be required, must be addressed in detail before conversion of engines to use these fuels is possible on any meaningful scale. We believe that the program being conducted at SwRI is capable of identifying and solving many of these problems."

The institute, Storment says, is bringing an enthusiastic attitude to the job, "confident that the problems associated with converting a class of highly developed engines such as the medium-speed diesels to practical operation on alternative fuels can be solved." At the same time, "knowledgeable people will realize that the current program is only a small step in this direction, and that much remains to be done. A more intensive effort, geared to solving the technical problems in a timely manner, is essential if the effects of future fuel availability crises are to be alleviated."

Storment notes, however, that there are a couple of deterrents at work here, one being the sheer variety involved in assessing possible future fuels—and another being "the absence of a national plan to reduce the number of these alternatives."

Under these circumstances, he concludes, "a concerted effort to widen the fuel tolerance of the locomotive diesel engine seems to be minimum insurance." ■

Postcript

In the post several months, additional testing work has been carried out which is not included in the preceding program status report. The principal such work has been:(1)

- Tests of diesel fuel operation using ethanol as the primary fuel and pilot diesel fuel to initiate combustion. Methodology used was similar to that described in the Railway Age article for similar tests with methanol. Findings were comparable.

- Tests were conducted using stabilized emulsions of both methanol and ethanol-in-diesel fuel. The emulsions tested contained approximately 7.5, 17.5 and 22.5% alcohol by BTU. It was found that thermal efficiency fell below baseline levels for all cases except one, and knocking was prevalent. Knock levels were prohibitively high when testing the 22.5% (by BTU) blends.

- Installation and instrumentation of the 12-cylinder EMD and GE engines was completed.

- Three low cetane number fuels blended at cetane numbers 38.8, 30.8 and 24 were tested in the 12-cylinder EMD engine in the even numbered notch positions plus Idle. A highly aromatic naptha (HAN) possessing a cetane number of approximately 17 was blended with No.2 diesel fuel to produce the desired cetane number. The performance data correlated quite well with previous low-cetane number tests on the 2-cylinder EMD engine. Minor reductions in brake thermal efficiency occurred as cetane number was decreased. No audible knock was detected when running on the 38.8 cetane number fuel but slight knocking was evident at 30.8 cetane. A dramatic increase in knock occurred with the 24 cetane number fuel.

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(1) Summarized from the program monthly progress reports.

APPENDIX B

Diesel Fuel Specifications

Figure 1

DIESEL FUEL SPECIFICATIONS

ASTM D-975

PROPERTY	ASTM NO. 1-D	ASTM NO.2-D	PROPOSED ASTM NO.3-D
Viscosity SUS @ 100°F	34.4	32.6 to 40.1	32.6 to 50.4
CETANE NO.	40	40	37
SULPHUR % WT	0.5	0.5	0.7
DISTILLATION:			
90% Min. °F		540	540
90% Max. °F	550	640	680
ASH % MAX.	0.01	0.01	0.01
CARBON RESIDUE (10% Residum) % Max.	0.15	0.35	0.40

Figure 2

CANADIAN GOVERNMENT DIESEL FUEL SPECIFICATION, 3-GP-6M

	Type AA	Type A	Type B	Type C	Type D	Method Méthode ASTM
Density, kg/L at 15°C	Report Indiquer	Report Indiquer	Report Indiquer	Report Indiquer	Report Indiquer	D 1298
Flash Point, °C, min.	40	40	52	56	56	D 93
Freezing Point, °C, max.	-48.5	–	–	–	–	D 2386
Cloud Point, °C, max.	–	-34	-23	-18	0	D 2500
Pour Point, °C, max.	-51	-39	-30	-24	-6	D 97*
Kinematic Viscosity 40°C, mm^2/s (cSt)** min.	1.2	1.4	1.7	1.8	2.0	D 445
max.	2.4	3.4	4.1	4.1	4.1	
Kinematic Viscosity at -35°C, mm^2/s (cSt)**	Report Indiquer	–	–	–	–	D 445
Distillation:						
50% recovered, °C	Report Indiquer	Report Indiquer	Report Indiquer	Report Indiquer	Report Indiquer	D 86
90% recovered, °C, max.	290	316	330	343	343	
End Point, °C, max.	300	343	371	371	371	
Water and Sediment, % vol., max.	0.01	0.01	0.05	0.05	0.05	D 1796
Total Acid Number, max.	0.10	0.10	0.10	0.10	0.10	D 974
Strong Acid Number, max.	Nil néant	Nil néant	Nil néant	Nil néant	Nil néant	D 974
Strong Base Number, max.	Nil néant	Nil néant	Nil néant	Nil néant	Nil néant	D 974
Sulphur, % mass, max.	0.2	0.5	1.0	1.0	1.0	D 1552
Corrosion, 3 h at 100°C, max.	No./N°	No./N°	No./N°	No./N°	No./N°	D 130
Carbon Residue (Ramsbottom), on 10% bottoms, % mass, max.	0.10	0.20	0.20	0.20	0.20	D 524
Ash, % mass, max.	0.005	0.01	0.01	0.01	0.01	D 482
Ignition Quality, Cetane No., min. or	40	40	40	47	45	D 613
Cetane Index, min.	40	40	40	50	45	D 976

Figure 3

ELECTRO-MOTIVE

M.I. 1750
*Rev. H

MAINTENANCE INSTRUCTION

DIESEL FUEL RECOMMENDATIONS ALL EMD AND FORMER CDED ENGINES

It has been and continues to be General Motors policy to manufacture engines that will operate satisfactorily on good quality commercial fuels that are regularly provided by the petroleum industry and meet the requirements of this maintenance instruction. As a result, EMD does not recommend the use of supplementary fuel additives marketed under such designations as conditioners, smoke suppressants, or graphitizers.

These recommendations, which are based on many years of operating experience, provide test limits for qualifying fuels being supplied to the engine. The inherently low level of maintenance required by our engines can best be realized if the engine fuel systems are supplied with fuel which meets these recommendations.

The cleanliness, quality, and uniformity of the fuels supplied to the engine fuel tanks are the

RECOMMENDED LIMITS FOR FUELS

As Supplied to EMD and Former CDED Engine Fuel Systems

Method Of Test	ASTM Designation	Limits
Calculated Cetane Number	D-976	40 (Min.)
90% Boiling Point	D-86	650° F (Max.)
Final Boiling Point	D-86	700° F (Max.)
Distillation Recovery	D-86	99.0% (Min.)
Total Sulfur	D-1552	0.50% (Max.) - Note 1
Corrosive Sulfur (3 hr. @ 212° F)	Modified D-130	No. 2 Strip Or Better
Conradson Carbon Residue (on 10% bottoms)	D-189	0.35% (Max.)
Water And Sediment	D-1796	0.05% (Max.)
Cloud And Pour Point	D-2500, D-97	Note 2
Flash Point	D-93	Note 3
Organic Chlorides	U.O.P. Method No. 588-65	20 ppm Total Chloride (Max.)-Note 4
Filtration Cleanliness Test (solid matter such as rust, cracking catalyst, and clays)	EMD Standard Laboratory Practice No. 102	1.3 mg. Per Liter (Max.) Of Ash Residue On 0.80 Micron Filter - Note 5.
Viscosity	D-445	32-45 SUS at 100° F (1.8 - 5.8 cs)
Ash, Weight %	D-482	0.02% (Max.)

*This bulletin is revised and supersedes *all* previous Fuel Oil Recommendation bulletins.

responsibilities of all who are involved in the manufacture, transportation, and handling of the fuels. The fuel should be free from acid, which, when in contact with any metal, forms enough soap to plug the fuel filters.

Electro-Motive will consult, upon request, with any user, supplier, or petroleum refiner on any question pertaining to fuels to be used in our engines.

NOTES ON TEST LIMITS:

1. For maximum engine life, the fuel sulfur content should not exceed the 0.5% recommended in this M.I.

   As fuel sulfur content increases, engine wear and maintenance costs will also increase. As a result, the user should carefully weigh the economics of less expensive high sulfur fuels against such increases in maintenance costs.

   The effect of high sulfur fuels on the diesel engine lubricant is also one of increased severity, and demands the use of high alkaline reserve lubricants as well as more frequent laboratory analysis and oil change intervals to assist in minimizing the effects of high sulfur fuels as well as insuring effective levels of engine protection. In this regard, EMD will assist, upon request, in the selection of a qualified lubricant formulated for such applications. Obviously, due considerations must be given to legal limits on fuel sulfur content where they apply.

2. The cloud and pour point of a fuel are measures of the formation of wax crystals and fluidity at low temperatures. To insure adequate flow through the fuel system filtration media during cold weather, the customer must specify the appropriate cloud and pour point requirements based on the lowest fuel system temperature expected. As a general rule, the cloud point should be 10° F (6° C) below the lowest expected fuel temperature to preclude the plugging of filtration media with wax precipitates.

3. Fuels normally used have minimum flash points of 150° F. Fuels with lower flash points can be used without affecting engine operation, however, fuel handling and storage may require added precautions.

4. The use of fuel containing organic chlorides results in rapid wear of chrome plated and iron surfaces in the combustion chamber. The presence of organic chlorides in fuel is rare but can occur from the use of halogenated dewaxing agents in cold weather pipeline operations, or from improper desalting of crude oils at an inexperienced refinery, followed by a reaction between the olefins and salt in the distillation unit. From past experiences, most refineries in the U.S.A. are alert to prevent the presence of chlorides in the fuel. Their precautions are now so automatic that cases of chlorides in the fuel seldom occur, and since routine control testing for chlorides is a time consuming procedure involving relatively large samples of fuel, it is not considered necessary in the United States.

   When testing for chlorides, EMD prefers the U.O.P. method No. 588-65, which employs the sodium biphenyl reduction procedure to obtain ppm of the organic chloride.

5. Until recently, "Filtration Cleanliness Tests" have not been generally employed or required in connection with diesel fuel. Experience has been that usual foreign contaminants, rust for instance, are removed by the filtration facilities at fueling stations, and by the filtration equipment normally supplied with engines. The increasing use of catalytically cracked fuels, however, has produced instances where minute catalyst fines were accidentally introduced into the diesel fuel production. These cannot be removed by the commercial filters used at fueling stations and on engines. The "Filtration Cleanliness Test" has been added to our diesel fuel recommendations to guard against contaminants of this nature.

   Because an involved laboratory procedure is required to distinguish the objectionable catalyst particles from other impurities, EMD suggests that all ashable material should not exceed 1.3 mg per liter of fuel when filtered through an 0.80 micron millipore paper. In those cases where contamination from catalyst fines is suspect, a sample of at least one gallon should be taken at the refinery where any significant ash content is most likely attributable to catalyst fines.

   In checking the cleanliness of diesel fuel samples taken from tank cars or customer fuel storage tanks, the sample should be taken by acceptable sampling methods. Cleanliness properties are then evaluated using EMD Standard Laboratory Practice No. 102 which utilizes the entire fuel sample as a measure of the ashable solids present in the fuel. This procedure has been appended to the M.I. to assist customers who may wish to perform their own analysis of fuel cleanliness.

Although the "Filtration Cleanliness Test" will check the fuel for ashable contaminants, it does not limit the amount of combustible organic contaminants. If fuel filters plug prematurely, the fuel should be checked for bacteria or fungus contamination and be treated with suitable biocide, if necessary.

EMD STANDARD LABORATORY PRACTICE NO. 102

DETERMINATION OF PARTICULATE CONTAMINANT IN FUEL OIL BY LABORATORY FILTRATION

Scope

This method covers time gravimetric procedure for determination of particulate contaminant in fuel oil by laboratory filtration.

Summary Of Method

A known volume of fuel is filtered through a preweighed membrane filter and the increase in membrane weight determined after washing and drying.

Apparatus

For determining the total contaminant: (Ref. Fig. 1).

1. Analytical balance, single or double-pan, whose precision standard deviation must be 0.07 mg or better.
2. Oven, of the static type (without fan assisted circulation), controlling to 90 ± 5° C.
3. Petri dish, approximately 125 mm in diameter with removable glass supports for membrane filters.
4. Forceps, flat-bladed with unserrated non-pointed tips.
5. Vacuum system.
6. Test membrane filters, plain 47 mm diameter, nominal pore size 0.8 µm.
7. Filtration apparatus, funnel and funnel base with a filter support, such that a membrane filter can be clamped between the sealing surfaces of the funnel and its base, by means of a metal clamp. (Millipore Filter Corp. apparatus.)
8. Muffle furnace, capable of maintaining a temperature of 775 ± 25° C.
9. Porcelain crucible, wide form, glazed throughout, 29 to 31 ml capacity, 46 to 49 mm (1.81" to 1.93") in rim diameter.

Reagents

Isopropyl Alcohol
N-Pentane (flushing fluid)
Distilled Water
Liquid Detergent, Water Soluble

Filtered Reagents

Filtered through a 0.45 µm membrane filter.

Preparation Of Apparatus And Sample Containers

All components of the filtration apparatus, sample containers, and their caps must be thoroughly cleaned and rinsed thoroughly with filtered reagents.

Laboratory Filtration And Total Contaminant Determination

Thoroughly clean the outside of the sample container in the region of the cap by washing with detergent and water, rinsing with tap water and filtered isopropyl alcohol. Shake the sample container vigorously for about 1/2 minute. Remove the cap and any external contaminant that may be present in the threads of the sample container by washing with filtered flushing fluid ensuring that none of the washings enter the container.

Pour some of the sample into the filter funnel. Apply vacuum to the flask and maintain a liquid head in the funnel until completion of filtration by suitable transference of the remainder of the sample, agitating the sample container before each addition. Disconnect the vacuum and record the volume of filtered sample.

Use 250 ml to 350 ml of filtered flushing fluid in this and succeeding paragraph. Wash the sample container with four 50 ml quantities of filtered flushing fluid to complete the transference of the contaminant to the membrane filter.

Wash down the inside of the funnel and outside joint between the funnel and filter base with filtered flushing fluid. With the vacuum applied, carefully remove the clamp and funnel. Wash the periphery of the membrane filter by directing a gentle stream of flushing fluid from the edge to the center, taking care not to wash any of the contaminant from the surface of the membrane filter. Maintain vacuum after the final washing only for the few seconds necessary to remove the excess flushing fluid from the membrane filter.

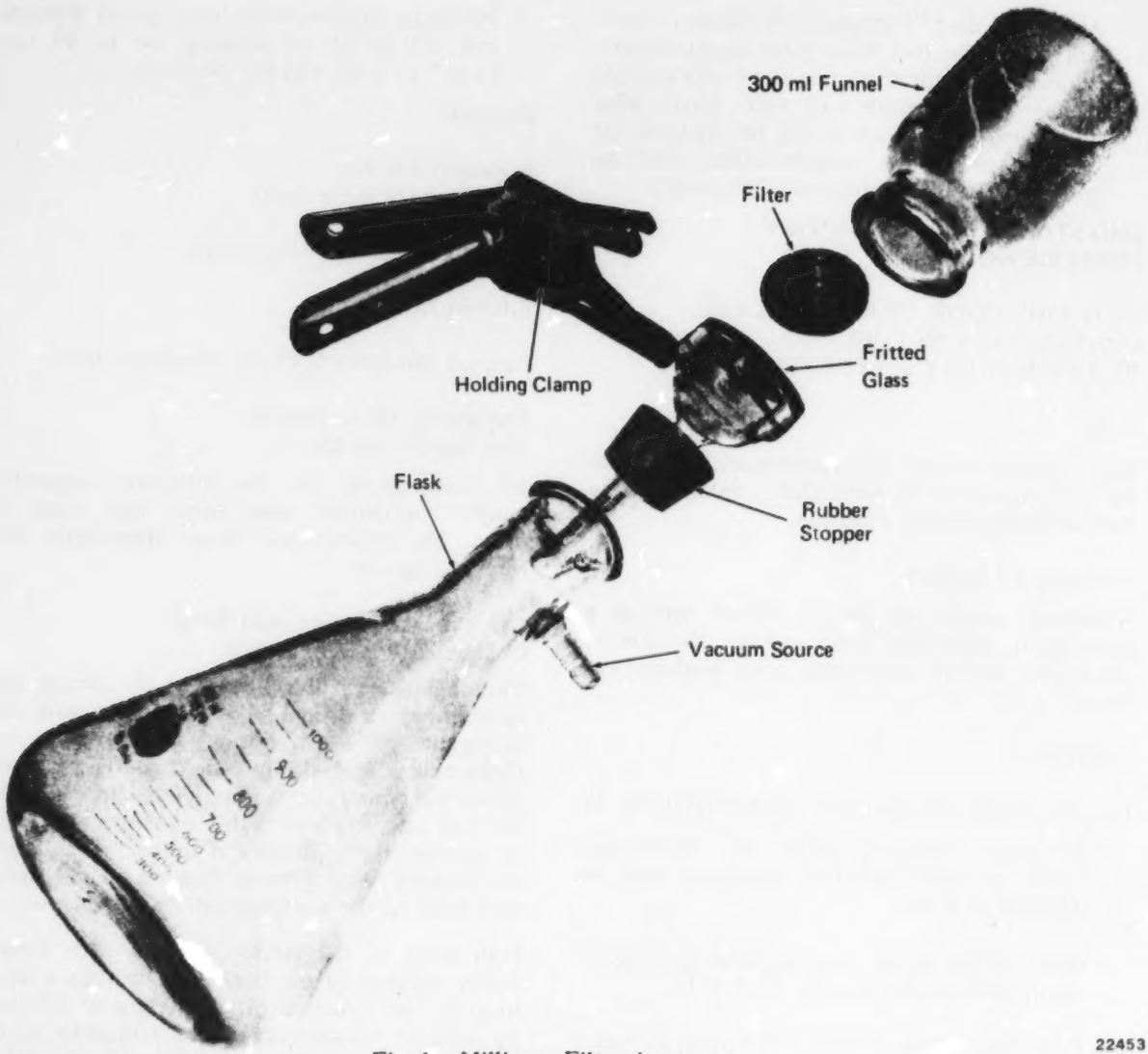

Fig. 1 – Millipore Filter Apparatus

Using the clean forceps, carefully remove the membrane filter from the filter base, and place it in a clean, covered petri dish. Dry and reweigh membrane filter, taking care not to disturb the contaminant on the surface of the membrane filter.

Calculation And Report Of Total Contaminant

Subtract the initial weight of the test membrane filter from the final weight. Report the results to the nearest 0.01 mg/liter as total contaminant mg/liter and also the sample volume used in the test.

Determination Of Non-Combustible Contaminant

Place the membrane filter in a clean porcelain crucible and soak with filtered isopropyl alcohol. Ignite the membrane filter until it is charred. Place the crucible containing the charred membrane filter in a muffle furnace at 775 ± 25° C for 1 hour, allow to cool, and weigh.

Calculation And Report Of Non-Combustible Contaminants

Divide the increase in the crucible weight by the volume of sample filtered and report the results to the nearest 0.01 mg/liter as, total ash mg/liter and also the volume used in the test.

Figure 4

MI-13001C

MLW INDUSTRIES
A DIVISION OF MLW-WORTHINGTON LIMITED

FUEL OIL SPECIFICATIONS

This bulletin provides recommendations for fuel oil to provide efficient low maintenance operation of the engines, as well as economical procurement of the fuel.

The fuel shall conform to the following requirements (ASTM Test Methods).

Cetane Number	40 min.
Distillation Temperature (90% Point)	675°F max.
Flash Point	125°F min.
Water and Sediment	0.10% max.
Conradson Carbon Residue (10% Bottoms)	0.35% max.
Ash	0.02% max.
Viscosity SSU @ 100°F	32-45
Sulphur	1.0% max.
Copper Strip Corrosion	No. 3 max.

NOTES:

1. For cold weather operation, the cloud point and pour point shall be 10°F below the prevailing ambient temperature, except where fuel oil heating facilities are provided.

2. Low atmospheric temperatures, as well as engines operating at very high altitudes, may require the use of fuels with a higher cetane rating.

3. Gum content of the fuel shall be at a level consistent with satisfactory engine performance.

4. Fuel oil, lubricating oil and engine service are mutually interdependent. A marked change in any one of these variables should be accompanied by careful engine observations to determine the effect of the change on engine condition.

5. Fuels not meeting the above requirements in all respects shall only be used after testing has established their affect on engine operation and maintenance.

6. "Fuel Oil, Diesel, Marine", to military specification MIL-F-16884 meets the above requirements.

*7. "Turbine Fuel", to grade JP-5 of military specification MIL-T-5624 is acceptable.

STANDBY SERVICE UNITS

*Standby units have a particular problem in that a comparably large fuel supply is required, but little is used during the weekly exercising of the engines.

All fuel oil tends to degrade during extended storage. The degradation, in general, is of two types. The first is oxidation and polymerization resulting in the formation of soluble and insoluble gums. The gums in the fuel can ultimately result in exhaust valve sticking during the unloaded idling of the engine during exercising. The second is bacteria growth at the interface of the fuel and water in the storage tank, resulting in clumps of bacteria in the fuel. This bacterial growth will result in fuel filter plugging, and has been known to cause fuel injection sticking.

Both of these degradation processes can be inhibited by the use of stability additives put into the fuel. The oxidation can be limited by certain proprietary anti-oxidants and dispersants, while the bacteria can be controlled by the use of biocides. However, fuels vary in their response to both the inhibitors, and testing will be required to determine the suitable dosage of the material. Also, it is known that the oxidation inhibitor cannot provide indefinite protection against the formation of the gums, and testing of the fuel would be required periodically to establish that the gums are within allowable limits. The use of the additives, particularly the biocide, may result in a conflict with environmental air regulations in some areas.

Data Subject To Change Without Notice

In view of the testing and difficulties involved in assuring proper stability of fuel oil with additives, the most satisfactory method for insuring good fuel at all times is to replace the fuel periodically. We recommend that arrangements be made with the fuel supplier to pump out the fuel at six month intervals and replace it with new fuel. The pumped out fuel can be used by the supplier in less critical applications or can be dumped into a bulk storage tank thereby diluting the contaminants. It is probable that this can be accomplished at less cost than trying to maintain the fuel in good condition by treatment.

Figure 5

C. N. R. SPECIFICATION

DIESEL FUEL OIL

DETAILED REQUIREMENTS (Continued)

5 Physical and Chemical Requirements

The physical and chemical requirements of the fuel oils shall be as follows:

	WINTER FUEL OILS						SUMMER FUEL OILS		Test Methods
	Grade C-40 Distillate	Grade C-34 Distillate	Grade C-30 Distillate	Grade C-30 Tar Sands[1]	Grade C-23 Distillate	Grade C-18 Distillate	Grade C-0 Distillate	Grade C-0 Tar Sands[2]	
Gravity, ° API	To be Reported								D 287
Viscosity at 40°C:									
Centistokes, min.	1.3[3]	1.5	1.6	1.8	1.7	2.1	2.1	1.8	D 445
max.	2.5	3.6	4.3	3.0	4.5	4.5	4.5	3.5	
Flash Point, °C, min.	40	40	50	45	50	50[4]	50	50[4]	D 93
Cetane Number, min., (Note 5)	40	40	40	(6)	40	40	40	(6)	D 613
Carbon Residue, % Mass max., (10% bottoms)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	D 189
Ash, % Mass, max.	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	D 482
Sulphur, % mass, max.	0.5	0.5	0.5	0.2	0.5	0.5	0.5	0.2	D 129
Water and Sediment, % Volume, max.	0.01	0.01	0.01	0.01	0.05	0.05	0.05	0.05	D 1796 (7)
Corrosion, max., (test tube - 3 hrs. 100°C)	1b	1b	1b	1b	1b	1b	1b	1b	D 130
Cloud Point, °C, max.	-40	-34	-30	(8)	-23	-18	0	(8)	D 2500
Pour point, °C, max.	To be Reported								D 97
Distillation,									D 86
Initial BP °C.	To be Reported								
10% over at °C, vol.	To be Reported								
50% " " °C, vol.	To be Reported								
90% " " °C, vol. max	300	315	325	295	335	345	345	320	
End Point, °C, max.	325	340	350	315	360	370	370	345	
Recovery, %, vol. min. .	97.5	97.5	97.5	97.5	97.5	97.5	97.5	97.5	

NOTES: (1) May be used in place of Grades C-18 and C-23 distillates where supply situation indicates.

(2) May be used in place of Grade C-0 distillate where supply situation indicates.

(3) When Grade C-40 fuel is to be used in small diesel engines in mechanical refrigerator cars, cabooses and other equipment the supplier must add 40 ppm by volume of Edwin Cooper Hitec E-515 to the fuel.

(4) May be used by CN Marine with Flash Point, °C, min. of 60.

(5) The Railway may estimate the Cetane number by determining the Calculated Cetane Index in accordance with ASTM Method D 976, Appendix II. In case of disagreement, Method D 613 shall govern.

(6) The Railway will require a report of Cetane number by ASTM D 613.

(7) ASTM Procedure D 1796 using centrifuge tube of D 2273.

(8) No suitable test; control obtained by limits on distillation.

Figure 6

CP Rail

MECHANICAL DEPARTMENT
MATERIAL SPECIFICATION -

SUBJECT: DIESEL ENGINE FUEL

SPECIFICATION NO. 138-D
PAGE 1 of 1
DATE April 1980
SUPERSEDES 138-C

1. SCOPE: This specification covers the physical properties of petroleum fuel oil for use in diesel locomotive engines. The period of April 1 to September 15 is classified as "Summer" and the period of September 16 to March 31 as "Winter".

2. REQUIREMENTS: (a) The diesel fuel must be free of all visible foreign matter and have a homogeneous appearance.

(b) The diesel fuel must preferably be a straight-run distillate with the necessary stability and compatibility characteristics. Details of test procedures used to determine these characteristics shall be supplied by the fuel supplier upon the request of CP Rail.

	ASTM Test Method	Summer Grade Min.	Summer Grade Max.	Winter Grade Min.	Winter Grade Max.
Viscosity @ 40°C, cSt	D-445	2.0	4.3	1.6	4.3
Flash Point, °C	D-93	40	*	40	*
Cloud Point, °C, (Note 1)	D-2500	*	0	*	-30
Pour Point, °C, (Note 1)	D-97	*	-4	*	-34
Cetane Number, (Note 2)	D-613	40	*	40	*
Sulphur, % mass	D-129	*	0.5	*	0.5
Sodium, ppm	*	*	2	*	2
Water & Sediment, % vol.	D-1796	*	0.05	*	0.05
Corrosion, 3 hrs., 100 °C	D-130	*	1b	*	1b
Carbon Residue, 10% bottoms, % mass	D-189	*	0.20	*	0.20
Distillation, 90% recovered, °C	D-86	*	345	*	325
Final Boiling Point, °C	D-86	*	370	*	350
Recovery, % vol.	D-86	98	*	98	*

Note 1. Flow improved fuels designed to meet equivalent performance criteria may also be used provided prior approval has been given.

Note 2. A calculated cetane index may be used for control purposes, in accordance with ASTM D-976, provided there is agreement with the supplier on the relationship between the methods. In case of disagreement, D-613 shall govern.

Engineer of Tests

Chief Mechanical Officer

APPENDIX C

Summary of Information Obtained at Meetings
with Major Oil Companies Augmented by
Data from the Hycarb Engineering Ltd. Report

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1. BACKGROUND

A study team comprised of CN Rail and CP Rail officers was established to predict the effects on the railways that may result from changes to the currently specified properties of diesel fuel, identify possible modifications to accommodate the changes and recommend investigations necessary for conversion to use of the new fuels. The study team held separate meetings in Montreal with representatives of each of the five major Canadian oil companies for the purpose of obtaining their views as to the short and medium term outlook for the continued supply of the necessary volumes of diesel locomotive fuel to current specifications.

Sept. 16, 1980 - Imperial Oil Ltd.
Oct. 2, 1980 - Texaco Canada Inc.
Oct. 22, 1980 - Shell Canada Ltd.
Oct. 30, 1980 - Suncor Inc.
Nov. 13, 1980 - Gulf Canada Ltd.

The following is a summary of the significant relevant information obtained at those meetings, augmented by data and information from the Hycarb Engineering Ltd. report, "Fuel Supply for Diesel Locomotives" prepared for the Transportation Development Centre of Transport Canada.

2. CRUDE OIL AND EQUIVALENT SUPPLY/DEMAND OUTLOOK

General

The ability of the petroleum industry to meet the demand for diesel, or for any petroleum product, is dependent amongst other things on an adequate supply of refinery feedstock and on sufficient refinery capacity having the conversion capability to meet the future product mix demand. Thus each of the oil companies with whom meetings were held discussed these elements of the matter. The aspect

of refinery feedstock supply, i.e. "crude oil and equivalent supply outlook" was treated in the greatest depth by Imperial Oil Limited and Shell Canada Limited. Also, those two companies very kindly furnished the study team with copies of their September 1980 submission to the National Energy Board (NEB)[1], from which additional information was available. Consequently, with respect to supply and demand forecasts, only data from Imperial, Shell and Hycarb have been included in this summary.

Crude Oil and Equivalent Supply Forecasts - Imperial and Shell

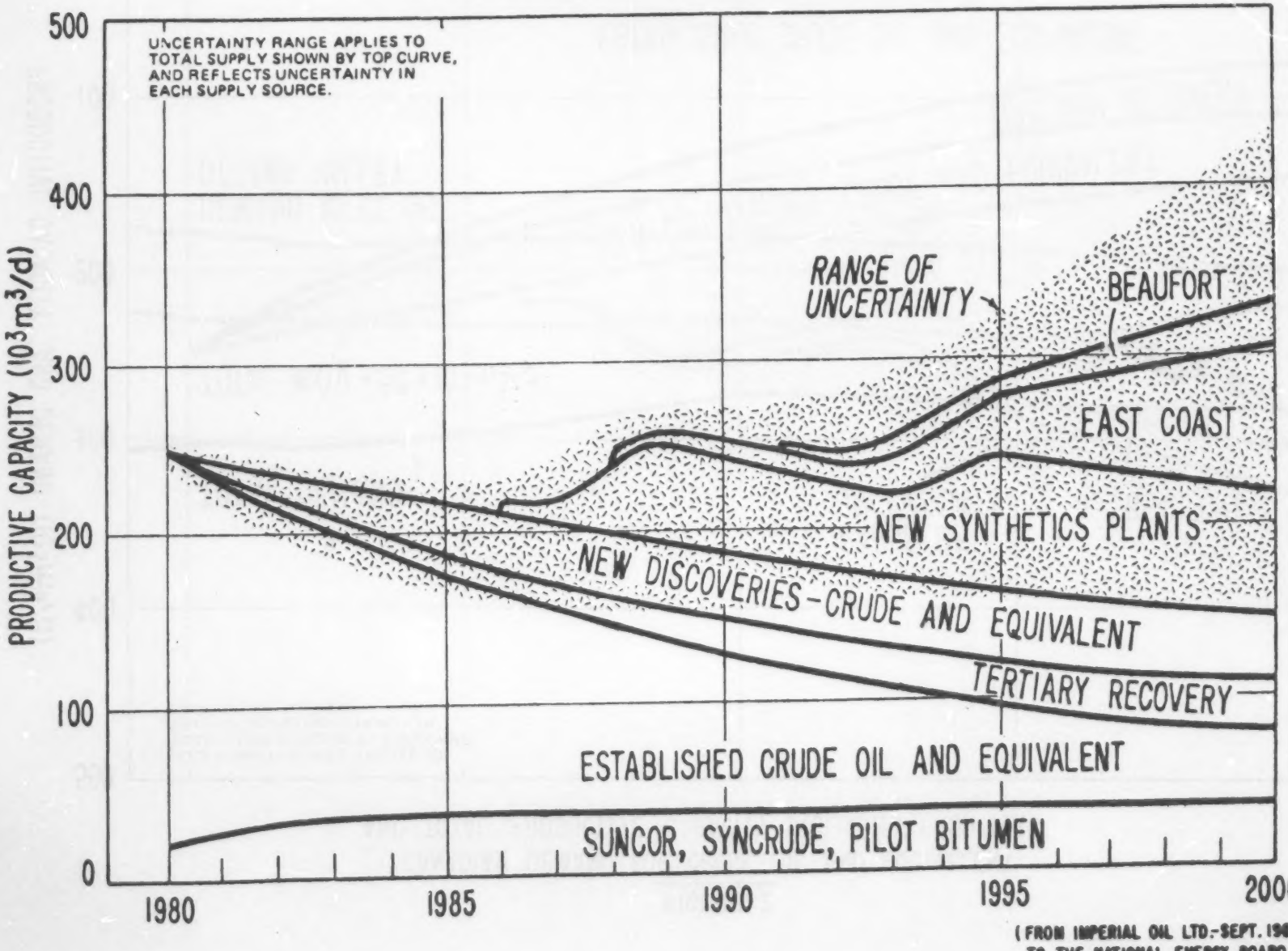
The Imperial and Shell forecasts of total Canadian productive capacity (and demand) are shown in Figures 1 through 4 (taken from their respective NEB submissions). As may be seen, the productive capacity (supply) forecasts of the two companies are quite similar. Both show a potential for the year 2000 in excess of 400,000 cu. meters per day (400 10^3 m^3 /day) taking all domestic sources into account.

In their submissions to the NEB both companies placed heavy emphasis on the need for resolution of current differences between levels of government regarding pricing of oil and revenue sharing, if potential productivity capacity is to be achieved. Both noted particularly, the importance of proceeding with the development of new synthetic plants, the high costs of those plants, and the need for a stable business environment to encourage the necessary investment, not only in those plants but also in new exploration and in tertiary recovery

(1) In the matter of an inquiry into the supply of oil, natural gas, and other forms of energy in relation to the domestic demand for all forms of energy, and the supply/demand balances for hydrocarbons and electricity.

FIGURE 1

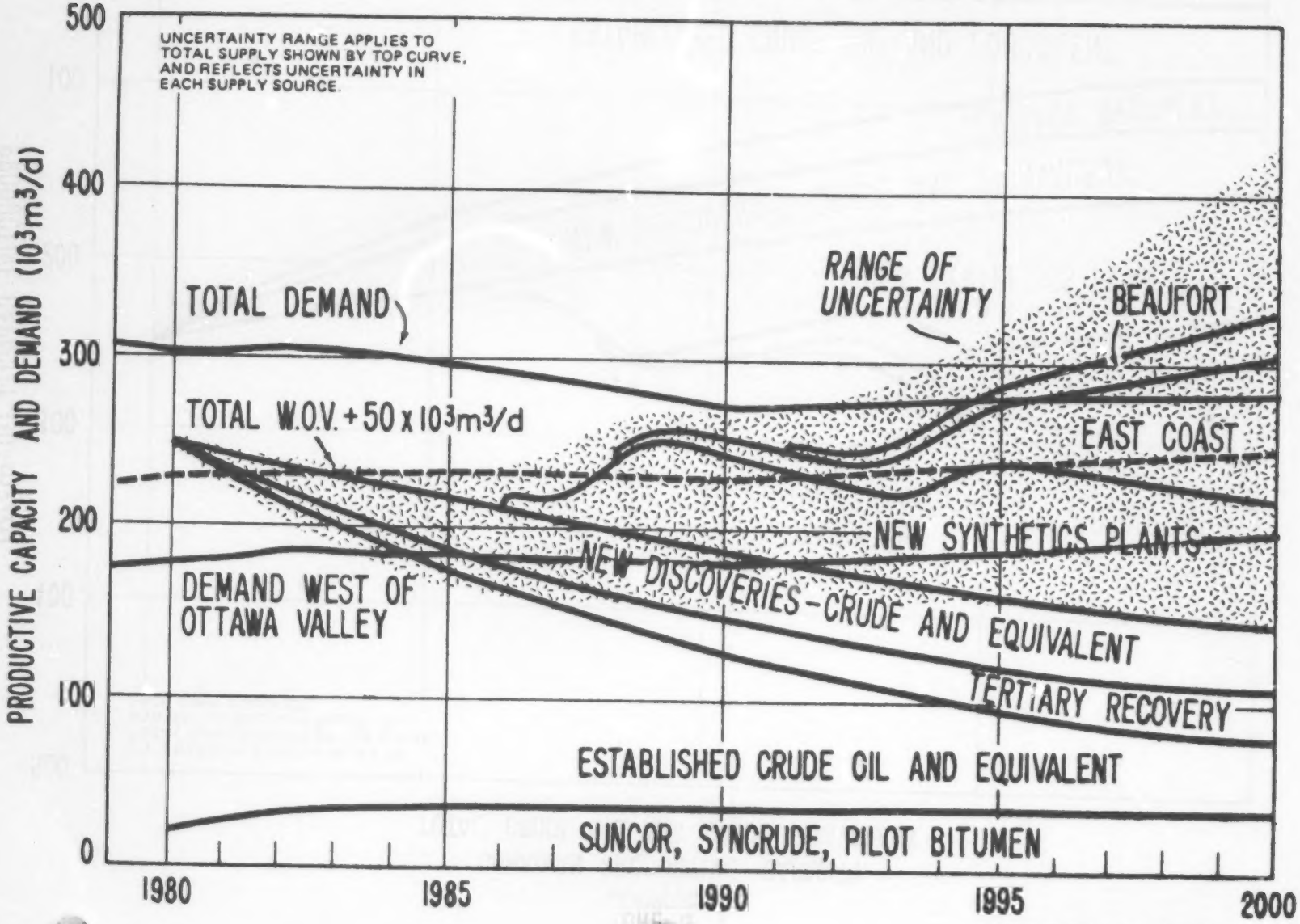
CANADIAN PRODUCTIVE CAPACITY
TOTAL CRUDE OIL AND CRUDE EQUIVALENT



(FROM IMPERIAL OIL LTD.-SEPT. 1980 SUBMISSION TO THE NATIONAL ENERGY BOARD)

FIGURE 2

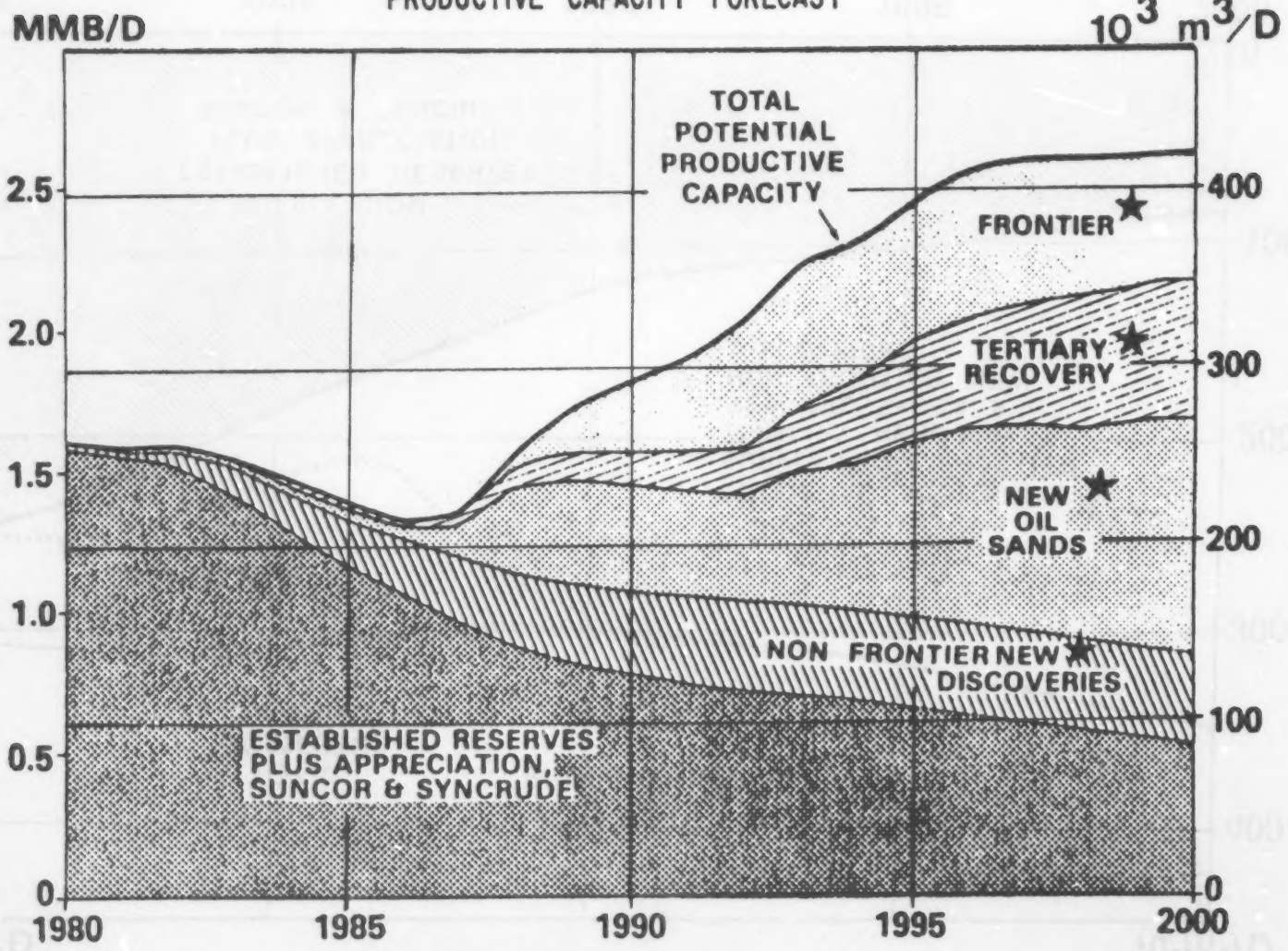
CANADIAN DEMAND FOR CRUDE OIL AND EQUIVALENT
AND TOTAL PRODUCTIVE CAPACITY INCLUDING FRONTIERS



(FROM IMPERIAL OIL LTD.-SEPT. [illegible] SUBMISSION TO THE NATIONAL ENERGY BOARD)

FIGURE 3

CANADA CRUDE OIL AND EQUIVALENT
PRODUCTIVE CAPACITY FORECAST

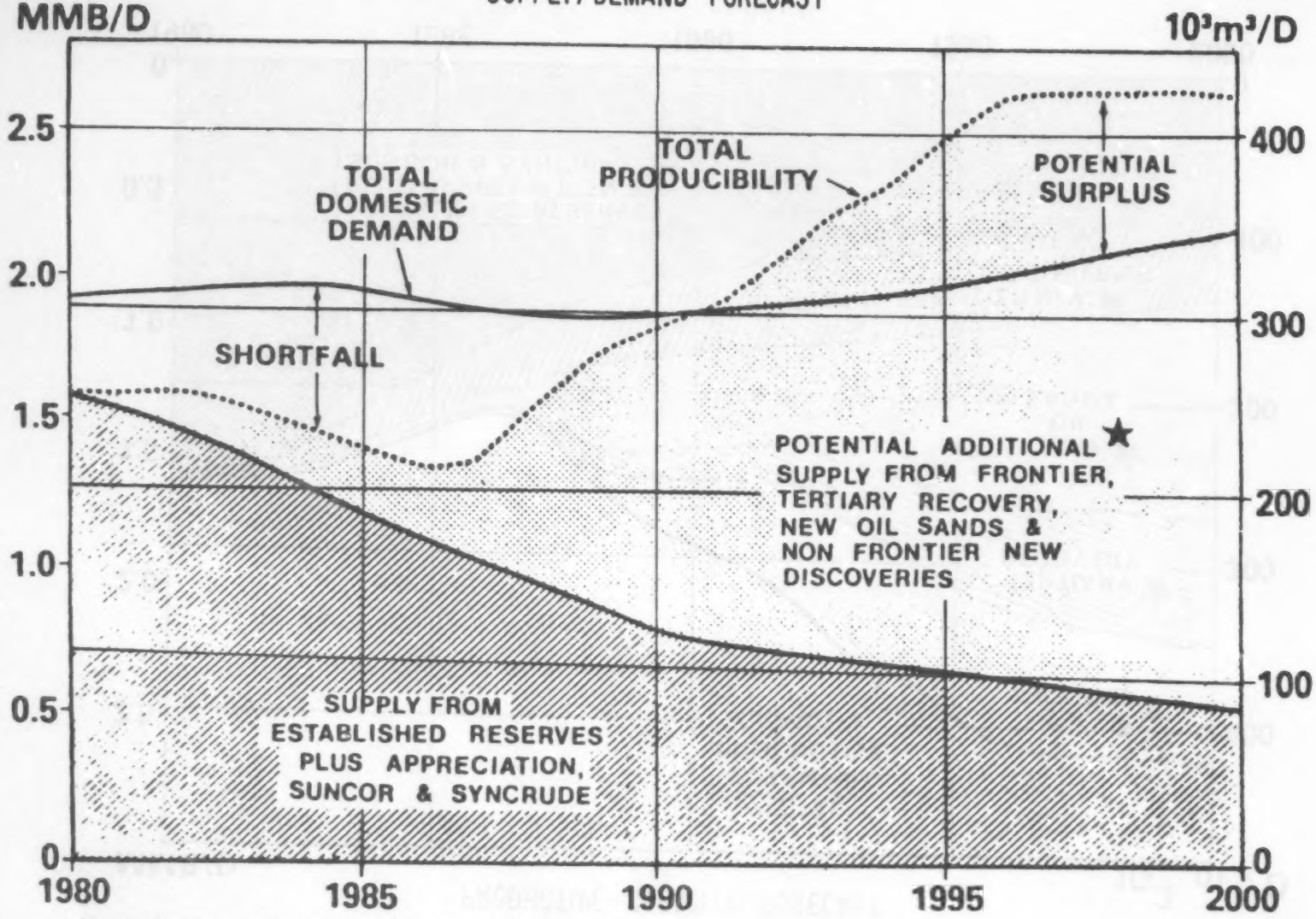


★ POTENTIAL SUPPLIES – DEPENDENT ON CREATION OF A BUSINESS ENVIRONMENT CONDUCIVE TO SUSTAINED, HIGH LEVEL EXPLORATION AND DEVELOPMENT OF THESE OIL SOURCES.

(FROM SHELL CANADA LTD.–SEPT. 1980 SUBMISSION TO THE NATIONAL ENERGY BOARD)

FIGURE 4

CANADA CRUDE OIL AND EQUIVALENT
SUPPLY/DEMAND FORECAST



★ DEPENDENT ON CREATION OF A BUSINESS ENVIRONMENT CONDUCIVE TO SUSTAINED HIGH LEVEL EXPLORATION AND DEVELOPMENT OF THESE OIL SOURCES.

(FROM SHELL CANADA LTD.- SEPT. 1980 SUBMISSION TO THE NATIONAL ENERGY BOARD)

processes. The difficulty of making supply projections is well illustrated by the following comments taken from Imperial's submission to the NEB:

"The prospects for supply additions have improved in the longer term provided there is a good investment climate. Oil has been discovered in the Beaufort Sea and the East Coast offshore. The recent performance of Syncrude demonstrates that the oil sands are a major potential oil source. Assessments of natural gas supply have continued to increase.

In spite of this improved outlook, however, the potential supply may not be realized because of current uncertainty about prices, revenue sharing, and the business investment climate. Production from existing fields may not meet expectations because the costs of producing these reserves are rising dramatically. Most new supply projects are capital intensive, have long lead times, and are subject to significant technological risk. The scale of projects has also increased dramatically. Tertiary recovery projects are very expensive and oil sands plants such as Cold Lake are now so large that no single company can handle one alone - each requires a number of participants. In today's environment, the potential oil sands plants or major tertiary projects cannot be considered a part of assured future supply. Stability in the rules of the game is absolutely essential."

Both Shell and Imperial believe that Canada has the potential to become self sufficient in oil and that this could occur by the early 1990's. (Gulf Canada foresees self sufficiency by about 1995). However, all three companies emphasize that for this to occur, resolution of the pricing and revenue sharing questions in a way which will encourage development is essential. Uncertainty as to this occurring is reflected in Imperial's "Range of Uncertainty" shown on their figures 1 and 2 and Shell's footnote on their figures 3 and 4.

Until self sufficiency is achieved, the shortfall between demand and domestic supply can of course only be made up with imported crude. Not surprisingly, none of the five companies chose to offer any assurance of the continuing security of those imports.

Crude Oil and Equivalent Supply Forecast - Hycarb Engineering

The Hycarb Engineering crude oil and equivalent supply forecast is shown in

Table 1. It is difficult to compare with the Imperial and Shell forecasts because it is not limited to only domestic productive capacity, but as may be seen, includes as the final item, net imports. To make comparison even more difficult, the net imports include, for the years 1985 and 1990, the forecast production of Canadian frontier oil. On the face of it at least, this inclusion of imports in Table 1 suggests that it is more a forecast of demand than supply, and in fact the total of 318.1 thousand c.m. for the year 1985 is obviously very close to the total domestic demand forecast by Shell for that year (refer to Figure 4), although somewhat higher than the Imperial Oil demand forecast for that year (figure 2). The Hycarb figure of 333.9 thousand c.m. for the year 1990 is appreciably higher than both the Imperial and Shell forecasts for either demand or productive capacity.

The Hycarb report notes that the synthetic crude projections in Table 1 represent the expanded productions of Syncrude Canada Ltd. (Syncrude) and Great Canadian Oil Sands (GCOS) and the construction and start-up of the Alsands tar sands plant and Esso Resources Canada Limited's (Esso) Cold Lake project.

3. DEMAND FORECASTS - ALL PETROLEUM PRODUCTS

The appendices to the Imperial and Shell submissions to the NEB include detailed tabular forecasts of total domestic petroleum products demand, for each geographic territory and for Canada as a whole, broken down by product. Somewhat similar data appear in the Hycarb report. The total Canada demand forecasts made by Imperial, Shell and Hycarb, were excerpted and are shown herein as Table 2, Petroleum Products Demand in Canada. The September 1978 NEB forecast, taken

TABLE 1

CANADIAN CRUDE OIL AND EQUIVALENT SUPPLY *
(Thousands of Cubic Metres Per Day)

Type	Actual(1) 1978	Forecast 1985	Forecast 1990
Conventional Light, Medium and Heavy Crude	119.5	190.8	159.0
Synthetic Crude	8.7	31.8	79.5
Pentanes Plus	18.9	20.7	15.9
LPG Mix from Gas Plants	2.7	3.2	3.2
Net Imports(2)	55.5	71.6	76.3
Total Supply	285.3	318.1	333.9

Notes: (1) Based on data from Statistics Canada Catalogue 26-006, December, 1978.

(2) 1978 data based on 97.8 x $10^3 m^3/D$ of imports less 42.3 x $10^3 m^3/D$ of crude oil exports. Forecast volumes include frontier oil.

*from Hycarb Engineering Ltd. report Fuel Supply for Diesel Locomotives October 1980.

TABLE 2

PETROLEUM PRODUCTS DEMAND IN CANADA

(10^3 m^3 per day)

	Actual		Forecast				
	1978	1979	1980	1985	1990	1995	2000
Hycarb Engineering Ltd. (October 1980)	270.4	280.8		293.8	303.9		
National Energy Board (Sept. 1978)	275.6	281.3		309.2	326.3		
Imperial Oil Limited (Sept. 1980)		297.7	297.6	289.5	277.7	282.8	288.3
Shell Canada Limited (Sept. 1980)		297.3	301.6	310.0	299.0	309.0	330.4

from the Hycarb report has also been included.

The two companies' forecasts are based on economic and demographic premises applied to each sector and product, and discussed in considerable detail in their NEB submissions. The outcome of their somewhat different premises is reflected in a steadily growing divergence in forecast total demand between the years 1980 and 2000. As may be seen from Table 2, by the year 2000, the Imperial forecast is some 42 thousand c.m. per day or approximately 15% lower than the Shell forecast. This is a substantial difference and serves as a useful reminder of the uncertainty surrounding the entire subject.

4. DEMAND FORECASTS - DIESEL FUEL

Assumed Demand Growth Rates

Hycarb Engineering notes that demands for diesel have proven to be higher than forecast by the NEB in their September 1978 report. For the Prairies, Hycarb increased the NEB forecast by 0.5% per year to reflect the high economic and population growth in Alberta and the high level of construction activity including the development of tar sands plants.

The Imperial and Shell forecasts for diesel fuel demand are part of their total energy demand forecasts. Their forecasts are based on assumptions regarding national economic growth, inflation, population, energy pricing and the application of various conservative measures. The combined influence of these and other factors was applied to develop energy demand within each of the major sectors, viz. Residential, Commercial, Transportation and Industrial.

Both companies have forecast a decline in demand for heating distillates, motor

gasoline and heavy fuel oil. The demand for both aviation gasoline and diesel fuel oil is expected to grow over the forecast period to the year 2000.

The forecast diesel fuel demand data for Canada have been excerpted from the Imperial and Shell submissions to the NEB, and from the Hycarb Engineering report, and consolidated in Table 3 of this summary. As may be seen from Table 3, Imperial are forecasting an approximate 100% increase in demand for road diesel between 1980 and 2000, an approximate 10% increase in demand for rail diesel and no increase in demand for marine diesel. For the same period, Shell are forecasting slightly more than a 200% increase in road diesel demand, an 80% increase in rail diesel demand and almost a 100% increase in marine diesel demand.

Total diesel demand is forecast by Imperial to increase by approximately 100% between 1980 and 2000. The Shell forecast is for an increase of 130%.

The forecast growth in total demand for diesel, combined with the decline in demand for motor gasoline, heating oil and heavy fuel oil will result in diesel fuel for all purposes growing from its present 14% of total petroleum products to almost 30% by the year 2000. (refer to next to last column in Table 3). This clearly illustrates the need for changes to the processing configuration of Canada's refineries if adequate quantities of diesel fuel of satisfactory quality are to be available. As previously noted, however, the forecast growth in demand for rail diesel is modest, with the result that although currently, railways account for approximately 15% of the total Canadian consumption of diesel fuel, this will drop to somewhere around 10 to 12% by the year 2000. (refer to final column of Table 3).

TABLE 3

DIESEL FUEL DEMAND IN CANADA

(10^3 m^3 /day)

	Transportation Sector				All Other	Total Diesel Demand	Diesel as % of Total Pet'm Product Demand	Rail as % of Total Dies. Demand
	Road	Rail	Marine	Total				
1978								
Hycarb Engineering Ltd.	11.7	6.3	2.8	20.8	14.7	35.5	13.3	18
Imperial Oil Limited								
Shell Canada Limited								
1979								
Hycarb Engineering Ltd.						40.1	14.3	
Imperial Oil Limited	19.7	7.2	3.0	29.9	10.7	40.6	13.6	17.7
Shell Canada Limited	14.1	7.1	2.7	23.9	16.4	40.3	13.5	17.6
1980								
Hycarb Engineering Ltd.								
Imperial Oil Limited	20.7	7.0	3.1	30.8	11.8	42.6	14.3	16.4
Shell Canada Limited	15.0	7.2	2.8	25.0	17.3	42.3	14.0	17.0
1985								
Hycarb Engineering Ltd.						50.8	17.3	
Imperial Oil Limited	24.5	7.5	3.1	35.0	16.2	51.2	17.7	14.6
Shell Canada Limited	20.9	8.8	3.4	33.1	22.0	55.1	17.8	16.0
1990								
Hycarb Engineering Ltd.						61.1	20.2	
Imperial Oil Limited	29.4	7.5	3.1	40.0	21.1	61.8	22.2	12.1
Shell Canada Limited	28.2	10.2	4.0	42.4	26.0	68.4	22.8	15.1
1995								
Hycarb Engineering Ltd.								
Imperial Oil Limited	34.6	7.7	3.1	45.4	29.0	74.4	26.3	10.3
Shell Canada Limited	37.1	11.5	4.7	53.3	28.3	81.6	26.4	14.1
2000								
Hycarb Engineering Ltd.								
Imperial Oil Limited	39.8	7.8	3.1	50.7	35	85.7	29.7	9.1
Shell Canada Limited	48.5	13.0	5.4	66.9	30.6	97.5	29.5	13.3

5 FUTURE SUPPLY OF DIESEL FUEL

Refinery Capacity

Production of sufficient diesel fuel and other petroleum products is not dependent simply on there being an adequate supply of refinery feedstock; i.e. crude oil and equivalent. Product shortages can also result from inadequate refinery capability caused by:

- insufficient crude running capacity
- lack of the necessary refinery processing configuration

The refinery processing configuration necessary is dependent simultaneously upon several factors. Principal amongst these are:

- the qualities of the feedstock
- the desired product mix
- the desired product specifications

Hycarb Engineering and the major oil companies all emphasized the increasing difficulties being faced by the refiners in producing an adequate supply of diesel fuel to current specifications because of changes to these parameters; more specifically:

- the declining availability of western Canadian light crude oil and the consequent need for the refiner to utilize increasing volumes of imported crudes (heavier and higher sulphur content) and/or Canadian synthetic crudes (high in aromatics.)
- the decreasing market demand for motor gasoline, heating oil and heavy fuel oil
- the increasing demand for aviation fuel and diesel fuel.

The Hycarb report includes an excellent discussion of the Canadian refinery situation and its influence on the future supply of diesel fuel. Highlights of that discussion are summarized in the Hycarb Summary Report. That summary follows.

"SUPPLY OF PETROLEUM PRODUCTS, WESTERN CANADA

The petroleum refining community in Alberta provides significant volumes of product to British Columbia, Saskatchewan, and Manitoba. Future growth in demands are forecast to be satisfied primarily by refinery additions in Alberta. For this reason, the four western Canadian provinces can be considered as one supply region.

Western Canadian Short-term Supply Situation (1980-1982)

The short-term is characterized by insufficient refining capacity. Diesel supplies, particularly low pour grades, will become extremely tight. A slight deficit (2%) in supply of low pour diesel is forecast by 1982. It is reasonable to expect that the refining industry will import product if available to alleviate any potential shortfalls in supply. Because the refining industry will be operating at 100% capacity utilization, operating problems could result in a more severe shortage.

Along with the potential shortfall in supply, it is forecast that the quality of the diesel pool will also suffer as the refining industry utilizes lower grade stocks to make up volume. It is forecast that cetane may drop two to three numbers below a cetane index of 45. Pour points on low pour grades are forecast to increase by two or three degrees Celsius (°C).

Western Canadian Long-term Supply Situation (1983+)

The petroleum refining industry in western Canada is currently planning for refinery additions primarily in the Edmonton region, which will more than adequately satisfy the growth in demand for petroleum products in western Canada.

The nature of the refining additions, hydrocracking, dewaxing for pour and cloud improvement, and upgrading of the distillates of synthetic crude, will ensure that the products produced will meet current specifications. Therefore, supply problems in western Canada will likely be limited to the short-term, and should not persist in the longer term."

"SUPPLY OF PETROLEUM PRODUCTS, EASTERN CANADA

Product supply is relatively integrated in eastern Canada, with product being moved by pipeline and marine. For purposes of summation, eastern Canada is treated as one supply region.

The eastern Canadian refining industry faces different conditions than that of western Canada. More than adequate crude throughput capacity exists. The problem is one of insufficient processing flexibility to adjust operations to produce the forecast product slate.

The eastern Canadian refineries are facing a significant decline in the demand for light fuel oil and heavy fuel oil, but a strong increase in the demand for diesel fuel.

Eastern Canadian Short-term Supply Situation (1980-1982)

The eastern Canadian refining community is forecast to have sufficient flexibility to meet the forecast requirements for gasoline and distillate. The eastern Canadian refining community is, however, considerably dependent on offshore crude supplies and disruptions could quickly affect the product supply.

Although the refining industry is forecast to produce sufficient volumes of distillate, the industry will have difficulty in producing adequate volumes of high quality diesel fuel. As the growth in diesel fuel continues, the refining industry will attempt to transfer more and more light fuel oil into the diesel pool to make up volume. It is forecast that the refining industry will maintain the current minimum cetane index specification of 45, but the resulting pour point may well suffer an increase of 3-4°C. The eastern Canadian refineries are faced with handling higher sulphur offshore crudes. The analysis indicated that the refining community has sufficient desulphurization capacity to meet current sulphur specifications.

Eastern Canadian Long-term Supply Situation(1983+)

By the mid-1980's, it is forecast that the refining industry will have a difficult time meeting current cetane specifications of diesel fuels. Without additional refinery investments, it is forecast that the cetane index of the diesel pool may drop by as much as three or four numbers below the current specification of a 45 cetane index.

The analysis has shown the refining industry as a whole has the capabilities of meeting current pour point specifications of diesel fuel in the longer term; however, the situation is extremely tight. The ability to meet pour point specifications will vary with the refiner's particular circumstance."

The comments and forecasts made by representatives of the oil companies during the meetings with the study team, generally confirmed Hycarb's assessment of the situation. Following are summaries of information relevant to the future supply of diesel fuel obtained from the oil companies during those meetings.

Imperial Oil Limited

Imperial believe that in the absence of an unpredictable crude oil supply crisis, they will be able to supply diesel fuel close to the railways' current specifications for the next two to three years. Beyond this point they believe the demand for high cetane number, low cloud point fuel will exceed supply and that significant cost advantages will be realized by the railways through relaxation of the relevant sections of the specifications.

Imperial foresee no other major problems in meeting railway diesel specifications. In the discussions, however, they raised the question of whether fuel having a final boiling point of 400°C is known to cause problems. They noted that although the current specification re final boiling point is not limiting supply, an increase would benefit the crude utilization efficiency.

Cetane

It was noted by Imperial representatives that although the Canadian railways' specifications currently call for a minimum value of 40, EMD specify a value equivalent to 35. The GCOS synthetic crude oil now used by both CN Rail and CP Rail in Western Canada has a cetane number of about 33 and is apprently used without problems related to this.

Imperial Oil representatives pointed out that as more tar sands crude oil is used in the West for refinery feedstock the cetane number of the diesel fuel produced will fall. In the East as the use of natural gas increases there will be a surplus of heating oil. Diesel fuel made from this will also have a cetane number lower than 40.

Imperial would like to use a cetane number improver additive and also note

that a reduction of 1 in cetane number would result in an increase in fuel for diesel engine use of between 2% and 3%.

In the longer term Imperial expect that diesel engined passenger cars will continue to require fuel with a high cetane number and that trucks will adapt to fuel with a cetane number of about 38.

Cloud Point

The demand for low pour and cloud point fuel will increase as diesel passenger car and jet fuel consumption increases. The additional diesel fuel produced by catalytic cracking of heating fuel will have a higher cloud point than currently acceptable by the railways.

Imperial would like to supply fuel having a cloud point based on the 2 1/2% Monthly Design Temperature. They estimate that this would result in their being able to provide fuel with a cloud point up to 5°F higher than at present at the beginning and end of the winter. In this way they would be able to store the low cloud point material for the most severe temperature conditions.

This approach could only be considered by the railways at points where the turn-over of fuel is rapid and the normal reserve is of the order of 2 or 3 weeks or less.

Imperial are also ready to offer a new "third generation" flow improver. This material acts to prevent the wax particles from coalescing into larger particles so that the wax which forms at temperatures below the cloud point will pass through the fuel filters. They believe that with its use, a fuel can be used at 15 - 23°F below the cloud point temperature.

The flow improver is added at the refinery in a concentration of 0.08% or 8 gallons in 10,000 gallons of fuel. The additive is purchased from Exxon in the U. S. A. and it was stated that similar materials are made by Tretolite (division of Petrolite Corporation) and Amoco Chemical Corporation.

Imperial also advocate the use of fuel heating systems such as the hot wells being applied by CP & CN. They expect truck operators to move in a similar direction. It was noted that in the long term if the use of fuel heaters allowed the use of summer grade fuel at all times then fuel facilities would require heating to allow handling in cold weather.

Texaco Canada Inc.

Texaco do not anticipate any significant change in the diesel fuel supply situation over the next two to three years providing there is no major interruption to the supply of imported crude. Their Halifax refinery (20,000 B.P.D.) operates wholly on Venezuelan crude and their Montreal refinery (74,500 B.P.D.) on about 40% Saudi Arabian crude and 60% light Western Canadian. The Nanticoke (95,000 B.P.D.) and Edmonton (24,000 B.P.D.) refineries operate on 100% Canadian. Montreal and Edmonton handle small amounts of synthetic crude (less than 1%) and Nanticoke about 5%.

Mexican crude was said to be heavier than the Venezuelan or Saudi Arabian and also higher in sulphur content. It will thus be a less suitable stock insofar as production of diesel fuel is concerned. In general, the heavier crudes, both domestic and foreign, are higher in sulphur content. The Texaco Montreal refinery has de-sulphurizing equipment, so if faced with handling more of such crude Texaco could do it there, diverting lighter crude to another refinery.

Sulphur is not a problem with present crudes. Presently, Texaco diesel fuel has about 0.3% sulphur content. The introduction of Mexican crude would increase sulphur content to about 0.5%.

Cetane

Although in the CN and CP specifications the cetane number specified is 40, the Texaco specification calls for 45 - to suit diesel automotive users. Texaco estimate that if the cetane number for railway fuel was to be lowered to 40, they could increase the supply by 25% by adding furnace oil which it is expected would be available due to falling demand. However, since Texaco does not have the facilities to store two different qualities of diesel fuel, the railways would have to provide their own storage for the 40 cetane fuel. It seems unlikely that the benefits to the railways would justify the cost of the storage tanks needed and so the railways could end up paying more (in total) for 40 cetane fuel than for the 45 cetane. Furthermore, the cloud point of the fuel would be higher due to the addition of the furnace oil. In any event, Texaco foresees no problem in meeting a cetane number of 40 over the next two to three years.

Cloud Point

Some difficulty is being experienced by Texaco in providing the necessary quantities of winter diesel fuel which meets railway specifications for cloud point temperature. Cloud point in their refinery specification varies by time of year and by refinery. For the period Oct. 1 to March 31, the maximum cloud point temperature permitted by their specification is -26°C, except at their Halifax refinery where for the period Oct. 1 to Oct. 30, it can be as high as -20°C.

A useful comparison of CN, CP, Texaco and ASTM 2-D specifications, prepared by Texaco, is included herein as Table 4.

Shell Canada Limited

Shell are confident that barring major disruptions in supply of fuelstocks they will be able to supply the railways with the necessary quantities of diesel fuel to current specifications over at least the next three years. Nevertheless, a number of factors are, and will continue, adversely affecting diesel fuel quantity, viz.

- high demand growth rate
- limited refining flexibility to reduce gasoline/distillate ratio (with the implication that the refineries must produce surplus gasoline in order to produce more distillate to current specifications)
- increased imports of heavy crudes (e.g. Mexican)
- increased substitution of gas for heating oil, releasing cracked stocks to augment diesel supplies (but these stocks are all aromatic, low cetane, high pour point with consequent denigrative effect on diesel quality).
- increased proportion of synthetic crudes (generally high aromatic low cetane) in refinery feedstocks.

The major impact of these factors will be to lower the cetane number and raise the cloud point. Synthetic crudes will tend to lower sulphur levels but the imported crudes will increase them; however, it is expected present specifications for sulphur can continue to be met.

Cetane

Shell representatives anticipate a growing use of ignition improvers to increase cetane number. They feel also that the industry should be moving towards the

TABLE 4

DIESEL FUEL SPECIFICATIONS*

	CNR 390-1C GRADE C-30 DISTILLATE	CPR 138-D WINTER	CPR 138-D SUMMER	TEXACO CANADA WINTER	TEXACO CANADA SUMMER	ASTM 2-D
Viscosity at 100°F, cSt	1.6-4.3	1.6-4.3	2.0-4.3	1.8-4.3	2.1-4.3	1.9-4.1
Flash Point, °C (°F) min.	50 (122)	40 (104)	40 (104)	52 (125)	52 (125)	52 (125)
Cetane Number, min.	40	40	40	45	45	40
Carbon Residue (10% Btms) %wt max.	0.15	0.20	0.20	0.15	0.15	0.35
Ash, %wt max.	0.02	---	---	0.01	0.01	0.01
Sulphur, % max.	0.50	0.50	0.50	0.50	0.50	0.50
Water & sediment, % vol., max.	0.01	0.05	0.05	0.02	0.02	0.05
Water, % vol., max	---	---	---	---	---	
Copper corrosion, 3 hrs. @ 212°F, max.	1b	1b	1b	1a	1a	3
Pour Point, °C (°F) max.		-34 (-29)	-4 (24)	-32 (-25)**	-6.7 (+20)**	
Cloud Point, °C (°F) max.	-30 (-22)	-30 (-22)	0 (32)	-26 (-15)**	-1.1 (+30)**	6°C above ambient temp.
Distillation, °C (°F)						
10%, max.				238 (460)	249 (480)	
50%, max.				271 (520)	282 (540)	
90%, max.	325 (617)	325 (617)	345 (653)	330 (625)	335 (635)	282-338
End Point, max.	350 (662)	350 (662)	370 (698)	343 (650)	352 (665)	(540-640)

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* Prepared by Texaco Canada Inc.

** See sheet 2 for seasonal changes

TABLE 4

DIESEL FUEL SPECIFICATIONS

TEXACO CANADA INC.

REFINERY SPECIFICATIONS POUR & CLOUD DIESEL CHIEF

SHIPPING DATE	HALIFAX POUR °C MAX.	HALIFAX CLOUD °C MAX.	MONTREAL NANTICOKE POUR °C MAX.	MONTREAL NANTICOKE CLOUD °C MAX.	EDMONTON POUR °C MAX.	EDMONTON CLOUD °C MAX.
Apr. 15 to Aug. 31	-6.7(+20)	-1.1(+30)	-6.7(+20)	-1.1(+30)	-6.7(+20)	-1.1(+30)
Sept. 1 to Sept. 15	-20.6(-5)	-15(+5)	-31(-25)	-26(-15)	-17.8(0)	-12.2(+10)
Sept. 16 to Sept. 30	-20.6(-5)	-15(+5)	-31(-25)	-26(-15)	-23.3(-10)	-17.8(0)
Oct. 1 to Oct. 31	-26(-15)	-20.6(-5)	-31.7(-25)	-26(-15)	-31.7(-25)	-26(-15)
Nov. 1 to Mar. 15	-31.7(-25)	-26(-15)	-31.7(-25)	-26(-15)	-31.7(-25)	-26(-15)
Mar. 16 to Apr. 14	-26(-15)	-23.3(-10)	-26(-15)	-23.3(-10)	-26(-15)	-23.3(-10)

DEGREES FAHRENHEIT IN BRACKETS

adoption of two cetane grades of diesel fuel - perhaps 35 for use in medium speed engines and 40 for others. They were not able to respond with certainty that the users of the lower quality fuel would enjoy a price advantage.

Cloud Point

Shell also anticipate a growing use of cold flow improvers to restrict the growth of wax crystals, thus enabling use of a higher cloud point fuel in low temperatures. They believe that a standardized test (such as the low temperature filterability test) would be more appropriate than cloud point as a measure of operability (on the basis that cloud point temperature will inevitably have to increase and be compensated for by flow improvers).

Gulf Canada Limited

Gulf foresees no significant change in Canadian diesel fuel quality for the next five years.

Shortages, if they occur, will be due in the West to insufficient refining capacity and in the East, to shortage of crude oil supply. This assessment corresponds to that made by the other major producers.

Beyond the five year time frame, Gulf foresees considerable change in diesel fuel. Their assumptions in that regard are as follows:

1. There could be wide variations in the quality of diesel fuels supplied in Canada. This would depend on the crude oil and process design of the individual refineries.

2. At some point in time there will be two grades of diesel fuel generally available. There will be a premium quality for diesel automobile use and for use as a starting fuel for equipment that ordinarily uses a lower quality fuel. There will also be a lower cetane, waxier fuel used by heavier equipment which is run more or less continuously.

3. We assume that the front end will not drop drastically since the heavy naptha will be required as reformer feed for unleaded gasoline. Rather we see the heavy end becoming considerably heavier. This will reduce the gas oil charge to the catalytic cracker and hence less catalytic cracked gasoline.

4. We assume that most diesel fuels will contain more cracked stock which again may contain higher boiling components. We are assuming that most of the cracked stock would be hydrogen treated.

5. We assume that fuels will contain more waxy heavy ends and hence may require more fuel handling precautions and will contain more flow improvers.

6. We, of course, assume that refineries will charge synthetic crudes to about 50% of their charge. The quality of the synthetic crude will be approximately the same as the currently available ones.

   Synthetic crude will, of course, not be charged uniformly by Canadian refineries.

7. The lighter distillate cuts from conventional crudes will be blended into jet fuel, stove oil and premium diesel to a large degree so will not be available for the second grade diesel fuel.

Presumably on the basis of these assumptions, Gulf developed a forecast of the future values for the various properties of railway diesel fuel. In the meeting with Gulf, "future" was defined as 10 years hence, or more. These, along with a listing of typical present values, (also developed by Gulf) are presented herein as Table 5. Discussion (subsequent to the meeting with Gulf) between one of the study team members and a senior Gulf technical officer in Toronto, confirmed that it is not expected that the values in the "Future" column of Table 5 would all obtain simultaneously. The values are intended to depict what is believed might be the worst case for each property, and are not intended to represent a complete fuel specification.

It is evident though, that the railways would be faced with problems if certain of the properties of future railway diesel fuel were to be as depicted in Table 5. Obviously cloud and pour point temperatures of +10°C and +5°C

TABLE 5

GULF CANADA INC.
FORECAST OF FUTURE DIESEL PROPERTIES

	Typical	Future
Density	.83-.86	0.87
Colour	0.5	3
Distillation		
10%	200-335	150°C
90%	270-340	360°C
FBP	285-350	400°C
Flash Point P-M	63	30°C
Cloud Pt.		+10°C
Pour Pt.		+5°C
Visc. at 40°C	1.9-2.9	4.0cSt
Water & Sediment		0.05
Sulphur	0.3	0.5
Ash	.005	0.01
Ramsbottom Carbon		
10% bottoms	0.10	0.35
TAN	.07	0.10
Corrosion 3 hr. @ 100°C	1a	1
Cetane Number	45	35
Aromatics % b.v.	15-30	40

respectively could not be tolerated in the absence of effective flow improver additives and extensive fuel heating facilities, both on board the locomotive and at wayside storage points. In fact, with a pour point of +5°C, it would be necessary to keep the fuel heated during transport in tank cars.

A flash point temperature of 30°C would be an additional problem from a safety standpoint. Presently, a flash point temperature of not less than 40°C is a regulatory requirement for diesel fuel in Canada.

It is not expected that the suggested cetane number of 35 for the future fuel would, in itself, present engine starting or operational problems.

The Gulf forecast of future diesel fuel quality appears to be appreciably more pessimistic than that of the other oil companies, or of Hycarb Engineering. It needs to be kept in mind though, as already noted, that Gulf foresees no significant change in Canadian diesel fuel quality for the next five years and that they foresee at least ten years before it might become necessary to adapt to fuel characteristics such as those in Table 5.

Suncor Inc. - Oil Sands Division

The gas oil sidestream produced by the Oil Sands Division of Suncor is purchased by the railways for use as diesel fuel. The gas oil sidestream constitutes approximately 10% of the total output of the plant and currently amounts to approximately 1.7 million bbls. per year or 740 m^3 daily. This represents in the order of 10% of the total current Canadian railway diesel fuel demand. The remaining 90% of the Oil Sands production is comprised of 3 products - kerosene, naptha and gas oil.

Suncor were considering changes which would result in increases to the present gas oil sidestream production level. One possibility would be to change the end point (final boiling point) from 650°F to 700°F. This would enable 1981 volume to be increased to 1.8 million bbls. and future annual production to be increased to 2.1 million bbls.

Another possibility is to change the end point to 750°F and API gravity to 25° - 35° (from its present 30° - 40°). These changes, combined with certain plant alterations and storage tank additions would enable progressive annual production increases of approximately 0.2 million barrels up to the year 1984 at which time it is estimated production would be at 2.5 million bbls. Finally, the same 1984 production level could be achieved through more costly plant alterations but leaving the product specifications unchanged.

Both of the possible changes to the fuel properties - viz. higher end point and lower specific gravity - would contribute to less complete combustion in the railway diesel engine. This would lead to higher emission levels, reduced engine cleanliness, higher ring groove deposits etc. With an end point of 700°, emissions would quite possibly not be critical; i.e. not violate present standards, but at 750°, would likely do so. Actual testing would of course be necessary to determine emission levels for either case. The problems of reduced engine cleanliness could be mitigated with crank case oil additives and by more frequent oil changes, both of which would result in increased maintenance costs, and reduced locomotive availability with probably ultimate increases in locomotive ownership.

It is anticipated by Suncor that production at the present site will not be

curtailed due to lack of raw material until the year 1995 - 2000. At that time it will be necessary either to relocate the plant or bring in raw material from another location, which if not too distant could be done by means of a conveyor system.

APPENDIX D

Study Terms of Reference

WORK STATEMENT

ALTERNATIVE FUELS FOR DIESEL LOCOMOTIVES

STUDY B EFFECTS ON ENGINE PERFORMANCE AND RAILWAY OPERATIONS

1. Introduction

With only minor exceptions, the approximately 4000 locomotives now in service on Canadian railways are powered by diesel engines. Together, they consume approximately 500 million gallons of diesel fuel annually. Because of this critical dependency on diesel fuel, and in recognition that present day uncertainties in the petroleum industry may lead to constraints in the continued production of diesel fuel to current specifications, the Railway Advisory Committee on research in the railway mode has proposed that studies be undertaken to investigate the possible need for, and consequences of utilizing, diesel-like fuels which have properties outside of the tolerance of current specifications.

The consequences of using such fuels may be significant. Modifications to the present diesel engine may be required in order to achieve satisfactory combustion characteristics and/or maintain acceptable levels of fuel economy and engine wear. Even with modifications, final efficiency and reliability may be less than at present, perhaps requiring changes in train operating procedures. Modifications to the railways' present system and facilities for the transportation, handling and storage of the different fuels might also be required. It will be apparent that exhaustive investigation of the foregoing would be a major undertaking. Such is not the intention of this project. No experimentation is to be included. The work is to be limited to investigation in only sufficient depth to gain, firstly, a reliable insight into whether and when the Canadian railway industry is likely to be required to accept changes in the specification for diesel fuel and the nature of those changes and, secondly, a general appreciation of the consequences of those changes. This latter information will be essential to both the railway and petroleum industries in assessing the implications of proposed refinery strategies. It will also provide some insight into the development of alternate fuel strategies. An obviously important aspect of changes in fuel specifications is the cost that would be incurred by the railways to carry out the physical and operating changes required to accommodate or alleviate the consequences of those changes. Accordingly, development of estimates of those costs is to be included as part of the investigation. An overall assessment of cost impact on the railway industry, although probably ultimately necessary, is not intended as a requirement of this study.

Currently in the United States, there are several in-depth research projects in progress, each directed generally to the investigation of the feasibility and consequences of using alternative fuels for the operation of railway (or other non-highway) diesel engines. Information on those projects has been assembled and is presented separately. It is the intention, as part of this investigation, to establish liaison with those projects with the ultimate purpose of establishing a program of complementary experiments and other investigations.

Inasmuch as adequate investigation of the whole subject will require expertise from both the refinery and railway industries, the work is to be conducted as two separate studies. The principal work within each can be summarized as follows:

STUDY A

Investigation of the changes that it is believed may occur by 1985, or soon thereafter, in the properties of diesel fuel produced by Canadian refineries and of the changes to the existing distribution system that may be required (if any) because of the new fuels.

STUDY B

Study B cannot begin until the preliminary conclusions of Study A are available. It is hoped that it could be completed within 15 months from the outset.

Prediction of the effects on engine performance and railway operating procedures that may result from a departure from the currently specified limits of the various properties of diesel fuel. Investigation of modifications and their costs that might be necessary to the present railway diesel engine to enable its efficient and reliable operation with the predicted new fuels, and of the changes and associated costs that might be necessary to railway operating procedures, including fuel transportation, handling and storage facilities.

2. Specific Project Objectives - Study B

a) To predict the effects on diesel engine performance, and on railway transportation, fuel storage facilities and handling procedures, of changes to the currently specified properties of diesel fuels and identify possible modifications to accommodate the changes.

b) To recommend a program of experimentation and other investigations necessary for successful conversion to use of new fuels by the railways.

3. Detailed Work Statement - Study B

Without limiting the generality of the foregoing, the work shall

include, but not necessarily be limited to, the following:

a) Examine the current specifications-- cetane number, viscosity, distillation range, pour point, cloud point, sulphur, etc.-- and associated test procedures for diesel fuel for the Canadian railways. Prepare an assessment of the effect of a departure from the limits placed on each parameter with particular reference to:

- effect on ignition and combustion performance
- effect on engine lubrication and wear
- effect on on-board filtration characteristics
- effect on on-board low temperature performance
- effect of wayside storage of fuels, including low temperature considerations, filtration performance, chemical stability and handling procedures
- effect of increased sulphur content from the standpoints of both corrosion and engine lubrication and the possibility of utilizing additives to counteract these effects.
- effect on exhaust emissions
- other effects on train operations

b) Evaluate currently used and other available fuel additives to determine:

- whether they might be effective in compensating for departure from current specifications
- how they will affect the cost of operations
- their likely side effects

c) Consult with locomotive manufacturers and operators to identify modifications to equipment which might accommodate or alleviate the consequences of departure from current fuel specifications. Estimate the costs and the time period required to make such modifications.

d) Identify the consequences of departure from current fuel specifications on railway operations, e.g. locomotive maintenance, train makeup, locomotive ownership, car cycles, fuel transportation, storage and handling, etc. Identify the changes that it is considered will be necessary to maintain the required level of system efficiency and reliability. Estimate the costs and the time period required to make those changes.

e) Establish liaison with Southwest Research Institute who are currently conducting tests on diesel engines and their fuels, and recommend a program of complementary experiments and investigations, where necessary, reflecting Canadian requirements or opportunities, such as low temperature operations.

f) Meet and consult with Study A personnel as necessary and as indicated on the study flow diagram in Appendix C.

4. Project Administration

The Railway Association of Canada will appoint a Project Officer to manage the project on its behalf. A Steering Committee consisting of TDC, the Chairman of TDC/RAC, CN Rail and CP Rail will be convened at the invitation of TDC to counsel the Project Officer, to monitor progress and to comment as necessary on the envisaged work to be done.

5. Project Control

The project shall be controlled by means of SPEC, or equivalent responsibility assignment and scheduling method. Budgets for each project element shall be prepared at the start of the project and monitored regularly to ensure resources available are compatible with estimates to complete the work.

6. Monthly Progress Reports

To facilitate the management of the project, three copies of concise monthly progress reports shall be submitted to the Project Officer, with a copy to TDC. The reports shall be typewritten, accompanied by one (1) SPEC, or equivalent, progress control chart and mailed in time to reach RAC offices by the tenth (10) working day following the end of the month reported on. Each report should contain the following items:

6.1 Current status of the work

6.2 A list of all persons actively working on the project and their functions

6.3 Work accomplished during the month

6.4 Problem areas, if any

6.5 Work to be addressed and expected to be achieved in the coming months, including estimates of percentage of work remaining, time remaining and funds remaining

6.6 Any action required by RAC or TDC.

6.7 Contact made with outside agencies or companies, or major visits planned in connection with the project

6.8 Other important information relevant to the project, as deemed appropriate.

7. Final Report

It is requested that twenty-five (25) copies of the final report

be submitted to the Railway Association of Canada. The report submissions schedule is as follows:

7.1 Draft submitted to the RAC Project Officer six (6) months after the date of the contract.

7.2 RAC comments to the contractor seven (7) months after the date of the contract.

7.3 Final report submitted eight (8) months after the date of the contract.

The draft and final reports shall be prepared and submitted in accordance with, and in the format of, that recommended in TDC's "Publication Standards for Consultant/Contractors TP 929 June 1977, to be provided by TDC.